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INDUSTRIAL LIGHTING IN WAR TIME

By H. C. WESTON, F.I.E.S. *(Member)*

(Paper read on Tuesday, October 22nd, 1940.)

The decisive part which industry will play in the present war is now so clearly recognised that the need of industry to be equipped for victory is as plain as that of the fighting forces. But the equipment of industry with lighting is not yet what it needs to be.

Effects of Lighting Restrictions Order on Interior of Factories.

Though not intended to do so, the Lighting Restrictions Order at once affected the interior lighting of many factories in several ways, namely:—

(i) By the total exclusion, or restricted admission, of natural light during the day, due to the method adopted for obscuring windows;

(ii) in some cases, by the adoption of the system of complementary lighting, which impairs natural lighting and involves artificial lighting by sodium or similarly coloured sources;

(iii) by extemporised modifications of existing installations to facilitate strict compliance with the Order;

(iv) in the early days of the war, by attempts to economise in the consumption of illuminants.

Where no preparations had been made in anticipation of lighting restrictions, the only practical measure applicable in many factories consisted in literally blacking out every window. So far as the cost only of obscuration is concerned this was also the cheapest method, as well as one which involved no daily dependence on the human factor for its application.

Undesirable consequences immediately ensued, particularly during night shifts. Ventilation was impaired so seriously that, in some cases, tropical temperatures were experienced and caused great discomfort and even strikes. This difficulty has been partly overcome by the provision of ventilator light traps on the lines laid down in BS/ARP 31, in the production of which members of the Society were largely instrumental, and in the Home Office pamphlet on " Factory Ventilation in the Black-out."

From the lighting viewpoint the total exclusion of daylight amounted to a change from day to night work for many workers who were previously quite unaccustomed to the latter. Apart from the psychological effects of this almost complete deprivation of daylight for at least five days of every week during the winter months, the artificial lighting provided in a number of factories was, and is still, physiologically inadequate and unsuitable for full-time work. It is not surprising that a number of complaints arose of soreness and inflammation of the eyes, and of headaches at the end of the day's work, older workers and those doing fine work being particularly affected. But for the general feeling that some inconvenience ought to, and must, be accepted in wartime, it is not unlikely that complaints of this nature would have been more widespread.

On the other hand, few complaints have been made by persons employed in factories which, by modern standards of practice, are well lighted, and no evidence has yet been forthcoming that artificial lighting is, in these circumstances, a factor likely to prejudice health even when it has to be used continuously throughout long working days.

There is no doubt that in many factories the provision made for artificial lighting has been very definitely influenced by the fact that its use is normally confined to short periods which do not, in the aggregate, exceed 15 per cent. of the total hours of work. Accordingly, no factor of safety has been allowed, and it has been tacitly assumed that if, occasionally, some strain is imposed on the visual capacities and tolerance of workers it is of less consequence than the additional expense of better lighting. Unwise as is this assumption in peace, it is certain that conditions whch are barely tolerable then are enemies within our gates in war.

At one large textile factory, where daylight has been entirely excluded, efficiency is reported to have dropped by 5 to 7½ per cent., and considerable unrest has occurred in spite of a compensatory wage increase of 7½ per cent. Though precise figures are not available, other cases of diminished production attributed to indifferent or bad lighting have been brought to the notice of trade unions. There has also occurred in some blacked-out factories an increase of nervous irritability among workers and supervisory staff, with consequent friction, which is anything but conducive to the general increase of efficiency so necessary in the present national emergency. Other changes in conditions of environment and work resulting from the war and the black-out

are, no doubt, partly responsible for this effect, but lighting has been blamed, probably quite justly, as a major factor in some cases.

War Productivity and Factory Lighting.

The recent great response of industry to the national need must not be thought to vindicate the *status quo* so far as lighting is concerned. During the first six months of the war, visits to factories led the author to the conclusion that, often, little unusual effort was being attempted.

Overtime and night shifts were worked, it is true, and by this means total output was increased, but not to the extent that would have occurred had the average worker improved on his normal rate of working. This normal rate, whenever the economic circumstances of the worker permit, is not unnaturally kept fairly well below the upper limit of real capacity, which is itself determined by the relations which hold between personal and impersonal factors. With conditions that are far from ideal there is, therefore, always the possibility of reaching higher, often quite unexpected, levels of personal efficiency in response to a powerful psychological stimulus.

It is in the nature of the human organism to hold in reserve a measure of capacity fully adequate to meet many abnormal demands, at least for short periods. But it would be foolish and dangerous to suppose that the draft now being drawn upon reserves, kept on the basis of existing environmental conditions, may not, in many cases, be taxing them almost to the limit. Evidence to the contrary is in fact accumulating.

To conclude that the factory workers' response to the recent exhortations of the Ministers of Supply and of Labour is evidence that there cannot be much wrong with existing conditions of lighting would not be justified unless this special effort is sustained for a long time. If it is now a maximum, with existing conditions of lighting, it is unlikely to be long sustained, for this is only possible for " normal," not maximum, effort. But better lighting may bring the effort required for the same, or even greater, productivity within the limits of normality.

Most of the research directed—during the inter-war years—to establishing the best conditions of industrial lighting has shown the need for something better than existing average practice. Conditions of lighting tried experimentally, but not realised in many factories, have been shown to evoke greater output, not at the expense of human energy reserves, but as a new normal level, not less, but perhaps more, within the new limit of capacity engendered.

Unprecedented demands must be made upon the productive capacity of workers in essential industries during war, especially if the time available for production is curtailed by frequent threats of air attack. Yet, though artificial lighting has to be used much more than in normal times, it has not, in general, been planned to give workers the fullest possible help in meeting these demands. Where deficiencies and faults existed in peace, they have become more apparent since exposure to them has been protracted. But in some cases bad lighting has been substituted for good. General lighting, for instance, has been abandoned, or greatly curtailed, and replaced by local lighting to prevent trouble due to imperfectly screened windows. Sometimes general lighting fittings have been modified by fitting skirts, thus spoiling the distribution and increasing diversity of illumination.

An early appeal for economy in coal consumption, and proposals for rationing both electricity and gas, encouraged the substitution of local for general lighting, and the abandonment of the latter where formerly both were used, because by so doing the necessary values of illumination on the work could be secured with less consumption. As temporary expedients these changes are excusable, but it cannot be over-emphasised that the shorter their life the better. They produce conditions of lighting which research and experience have shown to be undesirable, and which illuminating engineers accordingly condemn. Modern war involves so many apparently conflicting requirements, and among them both those that call for better factory lighting and those that tend to worsen it. Inside the factory these can, however be reconciled, and must be quickly, for the pace of war cannot be kept with any brake on industry. Compliance with black-out requirements need not, and should not, be secured by any method involving deterioration of conditions of interior lighting.

As well as the urgent need for speedy production, for which, as we know, good lighting is essential, material resources, some of which are necessarily curtailed, must be used to the fullest advantage. There must be a minimum of spoilt work, yet the standard of accuracy and quality to which work must conform is more rigorous in war than in peace. Thus a small mistake in the final stage, say, of an aircraft sub-assembly may mean its complete rejection, and lighting faults may easily occasion such

mistakes. If they occur, lives may be lost through delay in completing aircraft, but, in any case, the cost of material and labour thus wasted may exceed the difference of cost between indifferent and good lighting.

Change of Task and Personnel.

Operating against the realisation of the increased tempo demanded of industry in war, and against the avoidance of wasteful mistakes, are changes in the tasks and personnel of industry. These accentuate the importance of good lighting, and may invalidate factors of safety, where any have been used in planning installations for peace production.

The change of task is often not merely from the familiar to the unfamiliar, but also from fine to finer. Either or both add to the importance of vision, and therefore of lighting, as factors in production. The change of personnel involves the employment of workers transferred from non-essential industries, and of semi-skilled workers for more difficult tasks —a change which amounts only to the change of task already mentioned. But it also involves the employment of more women, including some quite unaccustomed to factory life, whose contentment and rapid acquisition of proficiency will depend partly on good conditions of lighting.

A further change affecting the lighting requirements of industry in war is the ageing of the average worker, due to the withdrawal of the younger men for military service.

Limitations of Lighting.

These considerations also make it important that the illuminating engineer should recognise that lighting has its limitations as a tool of industry. Some of the finest and most exacting tasks in the production of munitions give rise to eyestrain, however good the lighting may be, unless other aids to vision are used. Increasing illumination does not, of course, magnify fine detail, though, by increasing visual acuity, it has an equivalent effect. But above 100 ft.c. the assistance obtainable in this way is small, and considerable care is necessary if illuminations of this order are used to see that their value is not neutralised by direct or reflected glare.

Even with such illuminations the apparent size of the detail has sometimes to be magnified by reducing the distance between the work and the eyes as much as possible. The limit to this is set by the eyes' power of accommodation and convergence, which progressively decreases with age. In spite of high illumination, if maximum accommodation and convergence have to be used to reveal the necessary detail prolonged work will entail eyestrain. The attempt to avoid this involves frequent, if short, involuntary rest pauses,, during which the eyes are relaxed in distant vision. Thus production is inevitably slowed down.

For such fine work it is not enough to provide excellent lighting. Some optical aid should also be used, preferably in the form of special spectacles, which give some magnification and partly replace natural by artificial accommodation and convergence. A useful rule to bear in mind is that if, when lighting is provided according to the I.E.S. Code, workers find it necessary habitually to bring the eyes nearer than ten inches from their work the use of special spectacles should be suggested. By this means uneconomic lighting will be avoided and a more effective contribution made to the well-being and productivity of the worker.

Daylight.

The experience of the past year has laid emphasis on the already well-known fact that natural lighting is universally preferred to any artificial lighting commonly used in factories. Undoubtedly this is because its characteristics are generally most favourable to vision, but it is partly because the natural is desired for its own sake—because it is natural.

Many persons have, of course, long been accustomed to work by day in artificial light. Most, if not all, would much rather have natural lighting, but have long since accepted conditions they cannot change. But, for many more, the war has changed the natural and expected order of things, by which there is natural lighting by day and artificial lighting only by night.

This disturbance of the natural order itself provokes complaints which, however, are usually directed against the substitute for natural lighting. If this substitute is really good, complaints are certainly few; but even so, the admission of some daylight—useless, perhaps, as an aid to work—seems to be generally desired. This gives a visible assurance of daytime which the twelve-hour clock does not give.

It might be expected that admission of a small amount of daylight would merely keep the worker conscious of a greater need which cannot in present circumstances be satisfied. Psychologically, this

would be quite undesirable, but no effect of this kind seems to have occurred.

If small windows are opened or unobscured to serve as what may be termed "daylight tokens," it is important that they shall not be glare sources. Where artificial lighting is poor and the general interior brightness low, a small unobscured window near the normal line of vision is as undesirable as any other light source of relatively high brightness. Care needs to be taken in selecting the windows, or portions of windows, to be used as daylight tokens, and in controlling their brightness by the use of diffusing media if necessary.

Observation where the original black-out has been modified, by the installation of removable shutters, shows that much factory work can be done satisfactorily without artificial light if the unobscured window to floor area is in the ratio of about 1 to 8. A ratio of 1 to 12, or even 1 to 20, may suffice for roof-lighted factories. In modern factories of this type the ratio of window to floor area is often about 1 to 3, so that from two-thirds to three-quarters of the total window area can be permanently obscured without rendering natural lighting inadequate. The same may be true of factories having a similar ratio of unobstructed wall window to floor area, though, in these, illumination may be inadequate, even in peace time, if interior plant and machinery or structural features form extensive obstructions.

As far as possible, of course, the windows equipped with removable shutters should be selected to permit the best distribution of daylight. Unless there is good reason to the contrary, as where benches requiring good daylight are arranged against the walls, the upper rather than the lower part of wall windows should be uncovered.

Interior Appearance and Present Methods of Lighting.

The effect of obscuring windows by means of black paint is as well described as "blacking-in" as "blacking-out." The general appearance of the factory interior is depreciated, and a valuable amount of light which might be reflected into the shop is lost. There is a growing appreciation of this, and the interior surface of glazing is being whitened to an increasing extent.

Wherever the walls, floor, and roof of factories are clean and light in colour, and general lighting is installed, the appearance of the factory is greatly enhanced. Unfortunately, there are many factories where these conditions are not found.

But few, if any, factory interiors which normally have adequate natural lighting present so satisfying an appearance by night, or if "blacked-out," when lighted artificially on conventional industrial lines. One of the most noticeable features is the black top above the light sources, against which the latter present a high brightness contrast. With direct general lighting in a large workshop a forest of bright patches is seen set in a dark "sky," so unlike anything natural that to become oblivious of the means of lighting is impossible. One is constantly reminded that the lighting is artificial and very different from the natural lighting it replaces. This defect is not so noticeable where fittings with partly open tops are used, though it is not absent. Further improvement can be effected, without adding greatly to the total lighting load, by arranging a few units to illuminate the roof.

As yet, however, factory lighting has not been planned with sufficient regard for the simulation of natural conditions, even in respect of brightness distribution in the whole visual field. But this point has gained importance with the extensive substitution of artificial for natural factory lighting during the war, and it is a truism to say that the less any substitute differs from a real thing that is good the more readily is it accepted and desire for the real thing forgotten.

It is also a sound principle of good lighting that it should facilitate seeing without being ostentatious. In the factory, light sources are not ends in themselves, but merely means to an end, and the less obtrusive they are the better. But in many factories they are so obvious they seem almost to be saying, "See what fine fellows we are—don't forget we're here." Nothing like this is experienced with natural lighting, and should not be experienced with really good artificial lighting.

Comments and impressions received in the course of visits to a number of blacked-out factories suggest a psychological inadequacy and unsuitability of artificial factory lighting as generally practised at present. Though the best modern installations are the least open to this criticism, if artificial lighting is to be used for long periods we should not rest content with present methods. They are only good enough so long as nothing better is practicable.

Improvement of Factory Lighting.

In a very considerable number of factories, both large and small, improvement of lighting is necessary and, indeed, a matter of urgency, in the interests of welfare and efficiency on the industrial front.

Drastic alterations, or completely new installations, will be needed in some factories to secure compliance

with regulations giving effect to the recent recommendations of the Factory Lighting Committee in their Fifth Report. In others, improvement to this extent will be possible by making the best of existing equipment, and by the more or less liberal use of paint and limewash. Compliance with the new regulations in all factories, if it can be obtained quickly, will be a revolutionary achievement and one which should do much to sustain the cheerfulness and high productivity of our industrial army.

The most important new recommendation made in the Fifth Report* specifies an illumination of not less than 6 ft.c. at working level, or at 3 ft. above floor level, in all interior parts of factories where persons are regularly employed, without prejudice to any additional illumination which the nature of the work may require.

In making this recommendation the committee had in mind two considerations. First, that the illumination in actual workshops should be good enough to enable most ordinary work to be done comfortably and efficiently, and, secondly, that the amenities of the factory which contribute to the well-being of workers and to which, in normal times, many are accustomed by day, include a reasonable general level of brightness.

The second of these considerations prompted also the second recommendation. This proposes that throughout the interior parts of factories where persons are regularly employed, parts of walls, partitions, ceilings, tops of rooms, inside of windows where daylight is obscured and, as far as practicable, other structural fixtures which are less than 20 ft. above floor level shall be maintained light in colour. Where such surfaces can receive an appreciable amount of the light output of the installation it is clearly desirable that they should be reasonably good reflectors to assist in light utilisation, and to provide a satisfactory ratio of background to workfield brightness.

The only exception to the first recommendation (except for certain scheduled processes) is made in the case of workshops in which the light sources have necessarily to be mounted more than 25 ft. above the floor, or where the structure prevents the uniform provision of illumination to the 6 ft.c. level. In such cases the illumination is not to be less than 2 ft.c., and not less than 6 ft.c. where actual work is being done. The illumination is to be measured in the horizontal plane at a level of 3 ft. from the floor.

Thus, for the first time, a minimum illumination is prescribed which is high enough for tasks included in categories 6 and 7 of the I.E.S. Code, as well as for some tasks covered by category 5. This is a big step forward and, taken in conjunction with other recommendations in the Fourth and Fifth Reports, clearly shows the Departmental Committee's recognition both of the psychological or "feeling-tone" importance of lighting and its importance as an objective factor in relation to industrial efficiency, as well as to health and safety.

Under the Ministry of Supply Act emergency powers exist in virtue of which the Minister can require good lighting in vital war factories. This he has already done, and vital factories under the control of the Ministry, and of the Ministry of Aircraft Production, and the Admiralty, have been instructed to bring their lighting into line with I.E.S. recommendations.

It is clearly important that the necessary improvements in lighting shall be effected as soon as possible, and that competent advice and assistance shall be made available to factory occupiers to ensure the best results, as well as the most advantageous use of suitable existing equipment and of available supplies of new equipment. To provide, on a national basis, the necessary advisory and planning service the co-operation of the lighting industry is essential. Accordingly the electrical section of the industry has organised such a service with the approval of the Ministries concerned with supply and the Ministry of Labour and National service. This service operates on a non-commercial basis under the control of a Joint Lighting Committee appointed by the industry, but having an independent chairman in the person of Sir Duncan Wilson. Mr. J. S. Dow and the author are also independent members of this committee. To deal with gas-lighted factories the gas industry has set up a similar committee.

Illuminating engineers have already made important contributions to the solution of war-time problems, notably in respect of A.R.P. lighting. They now have a great opportunity to render national service in the improvement of factory lighting—an opportunity which also involves a great responsibility.

Industrial Lighting Practice—Present and Future.

Though no scientific method of determining the illumination desirable for specific tasks is yet available, the I.E.S. recommended values can be used as a guide without much fear that too low a standard of practice will be set.

A series of fittings, particularly designed for factory lighting, is available, and these are almost

* Summarised in "Light and Lighting," p. 125, No. 8, Vol. XXXIII, Aug., 1940.

exclusively used in providing installations designated as industrial. What this often amounts to is something rather narrowly utilitarian, which takes less account of amenity, in the full sense of the term, than might be the case. The illuminating engineer cannot always help this. He has difficulties to contend with, not the least of which is the price the user of lighting is prepared to pay.

But it will be a pity if factory lighting is allowed to become too stereotyped and if, for example, a particular solution of the glare problem, such as the cut-off fitting, should be relied on to the exclusion of other possible and more satisfactory solutions, such as low brightness units.

Methods of lighting reserved almost exclusively for other interiors could often be used with advantage in factories and, it is to be hoped, will be more readily applicable in the factories of the near future. Closer co-operation between architects, factory engineers, and lighting specialists should lead to structural design which gives wider scope for the use of different methods of artificial lighting and, in many cases, the nature of industrial processes need impose few restrictions on the architect's choice of interior structure. The term "industrial lighting" will have little meaning if development proceeds along these lines.

Lighting, even in factories, serves other ends besides the mere revealing of work and, while this is here its prime function, those who plan it should never forget that only in thought, and not in fact, is the work-man an isolate from the whole-man. It is not meant that the broad humanist outlook here suggested to the illuminating engineer should obscure the narrower functional outlook special requirements demand, but only that both are more compatible than is sometimes realised, and that the black-out seems to have revealed a tendency in current practice for the latter to obscure the former.

Realisation in practice of factory lighting approaching the humanistic and the mere work-light ideals has become easier by the recent addition of the 80-watt fluorescent tubular lamp to the resources of the illuminating engineer. The desirability of light sources of extended area and low brightness has long been recognised. In addition to these features, the new lamp emits light of spectral composition sufficiently resembling daylight to be both pleasing and specially suitable for many industrial situations and processes.

Its suitability for use in artificial windows, luminous panels, and lay-lights is obvious. Used in this way the most desirable features of natural lighting are so well simulated that attention is not attracted to the means for lighting. These are natural enough to be unobtrusive, and the deprivation of real daylight tends to be forgotten and to disappear from the workers' mental catalogue of real or imaginary grievances.

Artificial roof-lights using these lamps have been installed in a blacked-out factory and are greatly appreciated by the workers.* To provide a given illumination, the cost of an installation of this kind is considerably higher than an installation for ordinary tungsten lighting but, as with other discharge lamp installations, the current operating cost is lower.

This lamp, used in simple trough fittings, or bare if necessary, has many applications in the factory. Its brightness is well below the permissible maximum accepted by the Factory Lighting Committee, and it is not glaring unless the surrounding field brightness is usually low. Its length (5 ft.) is an advantage when using it to light drawing boards, benches, and individual machines, such as looms, since the whole of the operative's field of work is almost uniformly illuminated, and shadows formed by the operative are less dense than is the case when concentrated sources are used for local lighting. Glare due to reflection from specular surfaces is also reduced.

Where natural lighting has to be augmented continuously by artificial lighting, the lamp appears to be almost the ideal source, for the apparent colour difference between the natural and artificial sources is too small for the old objection to mixed lighting to arise. It is fortunate that a light source having such desirable characteristics should be available at the present time, even if the necessarily limited supplies must restrict its use to situations where its characteristics are likely to be of special value.

Local Lighting.

Emphasis has been laid chiefly on general lighting in the factory because, though always desirable on both physiological and psychological grounds, it is specially important now. The nervous strain of war must be mitigated by every means that can cheer us and brighten our outlook. In the environment of the factory worker, to which he is now exposed for more than the usual number of hours, perhaps nothing is more likely to make it difficult to maintain a cheerful

*See "Daytime Lighting of Blacked-out Factories," R. Maxted, B.E., A.M.I.E.E., and J. Bertram, B.Sc., A.M.I.E.E., "Electrical Times," Vol. 97, No. 2537, p. 481.

spirit, and an unwavering will to go on and give of his best, than the absence of general brightness.

But, of course, supplementary local lighting is not discounted. It is often essential, even when ample daylight is available for the general illumination of the factory, and in many cases the best installation, from every point of view, is one combining general and local lighting.

Low-voltage local lighting should find increasing favour during the war, since it offers considerable scope for the development of properly screened and well-placed built-in units.

For very fine work, adjustability of local lighting units is desirable, not only to permit change of direction of light, but to allow individual choice of illumination level. Widely different illuminations may be required by different individuals to develop the high degree of visual capacity necessary for such work.

A difficulty which arises when light sources are localised very close to the operator is the discomfort due to heat radiation. It is sometimes possible to avoid this by a more distant arrangement of the light source and the use of a mirror, or other reflecting surface, to ensure that sufficient light reaches the important area. Economy and convenience can both be served, in certain cases, by "tapping-off" local lighting from general sources in a similar way. By regulation, all local light sources must now be completely screened from the eyes of every person employed at a normal working place in factories.

Exterior Lighting.

The war has made it impossible to give effect to the recommendation in the Fourth Report of the Factory Lighting Committee concerning the lighting of exterior parts of factory premises. But the police can sanction emergency lighting giving very low illumination (0.002 ft.c.) in certain cases to facilitate access to work places. In any case the street lighting level of 0.0002 ft.c. is permissible for private roads on factory premises. If these illuminations are to be worth having, brightness contrasts over the area lighted should be carefully arranged to make the best use of the available light. Here the illuminating engineer needs also to be, in Dr. Paterson's words, a good "contrast engineer."

Maintenance.

Finally, the importance of maintaining the efficiency of lighting installations in wartime must be stressed. If many installations, when new, had only a low factor of safety for peace production, they will seriously impede the war effort if neglected now. Proper maintenance is, therefore, more important than ever. At the same time the difficulty of securing it has sometimes increased, if only for the reason that installations are in use for twenty-four hours a day. The time required for cleaning is being limited in some factories by equipping existing industrial units with glass visors.

DISCUSSION

The PRESIDENT mentioned that message had been received from Mr. A. W. Garrett, H.M. Chief Inspector of Factories, regretting inability to attend the meeting. Mr. H. E. Chasteney, the Deputy Chief Inspector, had, however, been able to be present and he would invite him to open the discussion.

Mr. H. E. CHASTENEY said he would not quarrel with the text with which the author opened the paper, viz., that industry would play a vital part in the war and that good industrial lighting could give very valuable aid towards winning it. The war called for 100 per cent. production and had brought home to us the need for the improvement in lighting which it was hoped would result from the new Lighting Regulations recently issued in draft.

The subject of industrial lighting had had very long consideration. The first Home Office Lighting Committee was set up in 1913, and presented its report in 1915. Although the standards suggested in that report represented an advance, one had only to glance at them to realise the difference of outlook that had come about since that date. The first recommendations were extremely modest compared with the recommendations of the Departmental Committee under the chairmanship of Sir Duncan Wilson in its fourth Report of 1938. The Committee had now reviewed the position in the light of war conditions and had felt justified in recommending still higher standards. No doubt that was partly due to the fact that in 1915 industrial lighting was not the exact science it is to-day, and that our resources in lighting and methods of illumination had enormously increased during the past twenty-five years; but it was also due to a complete change in outlook on the subject of industrial lighting. Instead of thinking of lighting merely in terms of the bare minimum necessary to see the work it was now regarded as essential that there should be reasonable lighting for seeing com-

fortably and without any strain, and, moreover, light that gave cheerful conditions. In other words, lighting was now regarded as an amenity and one which was specially necessary in trying times such as those we were now experiencing.

Referring to eye strain, Mr. Chasteney said that although there had been complaints he thought that these represented only a small proportion of the cases in which this condition arose, as many did not come to notice. Perhaps the older generation who had been accustomed all their lives to a rather poor standard of lighting did not think of complaining, but a large number of them were compelled to wear glasses because of the lighting conditions.

It was impossible to get adequate output with inadequate lighting, and it had been proved that a very considerable increase in output could be obtained with improved lighting. He suggested, however, that the increase in output would probably be more easily noticeable when going from poor lighting to good lighting than when going from good lighting to very good lighting. In the former case the increase was very marked, but in the latter case it might take a longer time before the improvement was recognised. There were many factors affecting production and it might be necessary to carry observations over a considerable period.

Whilst in full agreement with the author regarding the preservation of some natural lighting in blacked-out factories, wherever possible, we had to recognise that there was under present conditions a reluctance on the part of workers to carry on their work under a glazed roof. Glazing should, of course, be protected, but at the moment glass in roofs was being rapidly removed in many districts, sometimes by the management and sometimes by other agencies! We had, therefore, to face the fact that a good deal of glass was likely to be replaced by opaque weather-proof material, and we might get back to the permanent blackout in some cases. It was necessary to appreciate the need for specially good lighting in such cases, as a black-out factory was apt to be a gloomy and depressing place in the daytime when artificially lit to ordinary standards. This effect was largely psychological, but it was none the less real and called for the provision of a higher standard of illumination than the normal.

Doubtless there would be difficulties with material and labour in bringing about these improvements, and therefore it was necessary to make the best use of the material and labour which was available. Whilst sympathising with the author in his views on the aesthetic side and the use of special forms of lighting, it must be realised that in many cases the factory occupier would be driven to the more utilitarian and standardised methods on account of shortage of materials, if for no other reason. In the same way it was necessary to make the best use of existing equipment and layout where possible. Endorsing the author's remarks on maintenance, Mr. Chasteney said it had been the experience of Factory Inspectors that neglect to keep lighting equipment clean where dusty or dirty processes were carried on, often led to reduction of as much as 50 per cent. in efficiency.

In urging that close attention be paid to this whole problem, he expressed the view that not only would the results assist in winning the war, but equipment of the standard now proposed would be a permanent asset to industry in peace time.

Mr. R. MAXTED said that the author himself had inspired the experimental skylight installation mentioned in the paper, and those concerned wished to express their gratitude to him in that connection. Mr. Maxted said that he and his colleagues had been engaged on an investigation of "suitability" under war conditions, and that the obvious success of the artificial skylight referred to by Mr. Weston—and there were other installations—had given a very great impetus to the whole investigation. In the foundry there was not only better illumination, but the whole impression was of better ventilation and of a cooler working place. This introduction of artificial daylight was surprisingly successful and revealed the great potentialities of industrial lighting and the importance of psychological factors under war-time black-out conditions. [A number of slides were shown illustrating the application of 5-ft. fluorescent lamps to the local lighting of machines and work benches, and the effect upon workers was described.]

Referring to the occurrence of eyestrain and of physical and nervous fatigue in industrial establishments under war conditions, Mr. Maxted said that it had usually been taken for granted that eyestrain was mainly the result of general debility, due to operatives working seven days a week for months on end. Factory experiments, however, showed that where lighting was changed from economical peace-time practice to high quality lighting, not only did eyestrain disappear, but obvious signs of fatigue went in three or four days or a week. In other words, the correct interpretation of the coexistence of eyestrain and physical fatigue was bound to be the reverse of that commonly accepted; eyestrain was found to be

a very common and potent cause of physical fatigue and of nervous strain under the present conditions.

The point was emphasised that, under normal peace conditions, operatives worked under artificial lighting conditions for only 10 to 15 per cent. of their working time and had long periods of recuperation under natural lighting. Now, of course, the whole balance of things had been upset, and operatives were working for practically the whole time under artificial lighting, and there was, very often, no recuperative time.

Referring to one slide, Mr. Maxted pointed out that there was usually a ready acceptance of the severity of the visual task involved in inspection work, and that high quality lighting was commonly provided on inspection tables. An anomaly, however, was that operatives often had less satisfactory lighting than the inspectors, and there was a case in which the inspector had been invited to find defects under the conditions of lighting the workers had. It had been suggested that high quality lighting should be taken away from the inspectors!—a solution which might have far-reaching effects nowadays. A slide was then shown illustrating how high quality lighting had been provided for the operative, the remark being added that it was absurd to expect men to produce articles of precise dimensions and without defects under lighting conditions less satisfactory than those required by the inspectors.

Two slides were shown in reference to a factory designed especially for war work, and in which the lighting, planned in peace-time, was intended to meet black-out conditions. A general illumination of about 20 ft.c. had been provided by an overhead system, in which there was a certain amount of colour correction and some reduction in source brightness. Adjustable local lighting units were also used extensively. Within a few months of blacking out eyestrain was almost universal, and there was general fatigue and irritability. High quality localised lighting was installed experimentally for typical classes of work. In one case the work was the deburring of small gear wheels, and an operative whose eyesight was excellent was suffering from severe eyestrain, headaches which could not be relieved by normal means; and this operative was most dissatisfied with the unnatural limitation of his skill. With the introduction of really suitable lighting all this trouble disappeared. Due to a change in factory layout, this improved lighting was lost for a day or two and the old trouble immediately reappeared.

Referring to another instance of machine lighting, it was mentioned that, although the level of illumination from the overhead system was good, the verniers on the precision machines were practically unreadable owing to the reflected glare from the bright sources overhead.

The general finding in this factory was that, on precision machining and fine assembly work of metal parts, the reflected glare from light sources of high brightness caused very great eyestrain, which resulted in nervous irritability and psychological upsets. Operatives found the blacked-out factory most oppressive, and many of them developed headaches upon going out into daylight. These effects were eliminated by introducing suitable lighting of daylight quality.

An illustration was next shown of a multiple coil-winding machine which in peace-time was operated in daylight. When the factory was blacked-out high illuminations were provided with adjustable intensive local units. The operatives found it almost impossible to see the wire, due to reflected glare from the high brightness sources, and here again low brightness fluorescent lamps were used to give a daylight quality, which proved entirely satisfactory. A similar and much more vital problem arose in the winding of coils, using the very finest wire. Girls engaged on this work were chosen because of their good eyesight, and they were trained for months at the work, the training costing hundreds of pounds, Yet, after all this training, it was found that girls were leaving the work because of severe eyestrain and of the exacting nature of the work in general. Even under high quality lighting the work is still very exacting and irritating, and the use of daylight quality was of pronounced psychological value in giving a healthy appearance to the girls' faces and in generally obviating the oppressive effect of the black-out.

In all these investigations of suitability of industrial lighting under war conditions, the 5-ft. fluorescent lamp was used, since the low brightness cut out the strain of reflected glare, and the daylight colour quality had obvious psychological advantages.

Speaking of the economics of industrial lighting, Mr. Maxted referred to Mr. Blank's comment that the reports of Departmental Committees were followed by war. He suggested that this was more than a coincidence, and that the need for reform was more keenly felt than before war, because the armament programmes resulted in longer hours worked under artificial lighting, these conditions reaching a climax under actual war conditions. Re-

ferring in particular to war conditions, Mr. Maxted pointed out that the whole output of a blacked-out factory was dependent upon and controlled by artificial lighting. In the transition to war conditions the economics of factory lighting must, therefore, undergo a sharp change, and the costs of lighting should be properly related to the value of the entire output. Looking at industrial lighting in this way, it must be agreed that there has been far too great parsimony in the attitude towards the cost of factory lighting, and it could be shown that a much broader outlook on the whole question of the economics of lighting was essential. High quality lighting made possible the fullest industrial effort, and yet for too long we had regarded the cost of lighting on the basis of the actual cost of an installation rather than on the basis of the way in which the lighting affected the value of output.

Mr. R. O. ACKERLEY remarked that whilst he agreed with much that the author had said he rather felt that he was speaking of the industrial lighting of the future rather than industrial lighting in war time. Although a great deal of what the author advocated would doubtless come about, he did not think it would do so during the war, unless this was going on longer than they all hoped! It was necessary to bear in mind what had been said in the discussion in regard to making the most of existing materials, and things that did not call for new design and technique. In that way a great deal could be done towards improving psychological conditions, for example, by using inverted industrial reflectors for lighting roofs. Five-ft. mains lamps were excellent in the most important positions, but difficulties as regards production of these lamps did not hold out any hope of their general adoption—unless, again, the war should continue very much longer than was hoped.

It would be interesting to hear more from the author as to the greater use of existing types of fittings and what exactly he had in mind in connection with the treatment of north lighted factories. One of the industrial difficulties of the lighting engineer was that the majority of factories had been planned from the daylight standpoint of admission of daylight. This made it extremely difficult to deal with the artificial lighting of such factories under blackout conditions.

Although at the moment one had to think of these problems in relation to war conditions, there was no reason why some consideration should not also be paid to the future. He would, therefore, like to have the author's view in regard to the factory of the future, and in particular the best method of lighting artificially a factory dependent on a north light during the daytime.

Mr. E. W. MURRAY said that whilst there was a great deal to be said in favour of the system of lighting utilising large areas of illuminant having a low surface brightness, a great deal more might be done with existing installations by fitting some form of translucent screen below the light sources to give a sort of skylight effect. Inadequately shaded lamps often create extremely bad glare, but this point would be avoided if such a screen was fitted between the workers and the light itself. A number of instances have been reported by factory inspectors in which there has not only been an increased output, but also increased wages under piece-work conditions, where steps of this kind had been taken. These instances, however, apply to peace time, but there is no reason why the same conditions should not be utilised in the time of war.

Mr. R. W. DANIEL expressed the view that in vulnerable areas it would be necessary to contemplate the complete extinction of daylight from factories. The gloomy appearance of a factory, on entering it from the bright light outside, was due to the fact that sufficient trouble was not taken to whiten the interior. It was not possible to require that that should be done, under the Factory Lighting Regulations, but it was up to lighting engineers to emphasise its value and to do everything in their power to persuade managements to attach importance to painting in a light colour. An interesting experience had been met in the case of certain nitro-glycerine huts. Each hut was about 15 ft. or 20 ft. square, and was lighted by a type of bulkhead fitting, which did not provide very good distribution. Nevertheless, from $\frac{1}{2}$ to 1 ft.c. produced very cheerful surroundings, owing to the extremely light colour of the walls.

So far as the fluorescent tube system of lighting was concerned, he did not think that that should be considered a panacea for all factories in time of war. After all, it was rather an awkward shape at present, and if he were a managing director he might be expected to agree to put one or more into the board room for the directors, but suggest that the salesman would probably come back later, anyway, with a

simpler design for factory purposes. This might well be a very general attitude.

In connection with north lights, he did not think it was a practical proposition to expect a management to spend large sums of money in fitting an arrangement into the glass roof to provide adequate artificial illumination under war conditions when they sincerely hoped they would be able to return to daylight within the not too distant future. Perhaps a way out of the difficulty would be to fit an arrangement such as this to the underside of the sawtooth on a pivot, so that it could be lowered to a slightly flatter angle by day and pulled up hard against the roof by night.

On the maintenance question, he said he had often been depressed by the manner in which managements spent large sums of money on a lighting equipment, but failed to make adequate arrangements for maintenance.

On the subject of making best use of equipments, he thought that if the higher standard of lighting laid down by the new regulations were to be obtained in the immediate future, as it must, it would be necessary to do a great deal of improvisation with existing equipment, and not to expect the ideal arrangement which one might demand in normal times.

Mr. A. E. Iliffe said he had hoped to hear a little more on the question of the improvisation of existing installations, because it would be impossible in many factories to adopt the ideal system of tubular lighting which had been referred to and which involved the use of steel, which was restricted except for the most important national purposes. The fluorescent 5-ft. fittings used anything from six to nine times the raw material of the ordinary 200-watt lamp. Again, there was the question of the supply of lamps and fittings, because in these days of bombing it was possible that the whole of the equipment would be brought down and would have to be replaced very quickly. Therefore, the illuminating engineer should put in a system which could be replaced quickly in such circumstances. The replacement of those 5-ft. lamps, of course, could not be effected so quickly as with the ordinary 200-watt lamps, although the illumination given by the latter might not be comparable with that of the newer lamp.

Commenting on the use of lay-lights, he pointed out that some factories were developing a sand-bag system whereby the machine-minder was able to get down behind his machine and, therefore, would not prefer to have a glass lay-light system above the machines. There was a psychological effect and the system enabled the men to get on with their work continuously.

Referring to local lighting, he suggested that there was a danger of having too much in one particular place, and although it might give one operative the light he required, it might interfere with other operatives working near by. At the same time, he suggested that the lighting should be so arranged that the operatives themselves should not be able to adapt it in any way for their own particular purposes, again for fear of interfering with others working near by.

Mr. Arthur Cunnington expressed satisfaction that, owing to the urgency of this matter, an Advisory Planning Service had already been put into operation; and he added that it was characteristic of the industry that it had got to work so quickly in helping factory executives to decide what to do. The question of improving factory lighting for war conditions was not just one of selling a lot of fittings and putting them in quickly. All these cases had to be considered on their merits, and experienced people must go into the factories and see what the conditions were, endeavouring to alter them as little as possible, in order to maintain the highest possible production. It was not desirable, or even possible, to make an enormously expensive change all over the country. Some factories might be equipped with the 5-ft. fluorescent lamps which had been referred to, but others would have to be treated in an entirely different manner. There should be a real illuminating engineering control in the matter of giving advice to factory executives.

Referring to maintenance, he said the difficulty was that frequently too little thought was given to it in the early stages of design. It was essential to put in fittings of such type that the maintenance could be carried on without interfering seriously with production. In other words, the installation should be so designed that the highest possible efficiency of the light sources could be maintained over long intervals. In some cases large sources of light might be advisable, whereas in others small local sources would have to be adopted. All these considerations must be given due weight in advising an executive on the type of installation to be adopted.

Mr. F. Charles Raphael said the author had made use, rather vaguely, of the old-fashioned engineering term " factor of safety," and it would be interesting

if he would explain exactly what he meant. Did he mean what was often called the "depreciation factor" or the old-fashioned factor of safety which engineers employed to some extent even to-day? The engineer realised that he might have made a mistake in his calculations, and he also realised that his material might not be all that it should, and therefore he adopted what was known as the "factor of safety." Was that the factor of safety which the author meant? For instance, if one were working to 6 ft.c., did he mean that there should be a factor of safety of 2, 3, or 4, or did he mean simply that there should be just a small margin for extinction of lamps and as a substitute for the depreciation factor? That was an important point, because if the factor of safety were applied from the old-fashioned engineering point of view it would mean an enormous increase in the energy required for lighting, and an existing installation would have to be very greatly modified, and in many cases it would be necessary to start all over again. Moreover, it might result in such a demand on the supply authorities that they could not give the necessary supply.

Speaking of depreciation and maintenance, he said that when working twenty-four hours a day it was of no use thinking of very frequent cleaning of lamps and fittings, and therefore it was necessary to arrange for the equipment to be of such a nature that with long intervals between cleaning there was very little depreciation in efficiency. He added that he had seen figures a short time ago of the cost of cleaning, and they represented, to his surprise, a very large percentage of the energy cost.

SIR DUNCAN WILSON, asked by the President to sum up the discussion, said he did not wish to add anything to what the author had said, but there were a few points he would like to emphasise. The first was the use of special spectacles for very fine work. It had always been rather a surprise to him that the adoption of such spectacles had not been carried farther than it had, and even Mr. Maxted had omitted any reference to them. About a year ago he was in a hosiery factory where such spectacles had been tried for very fine work and proved so successful that they were then supplied to all the operatives. These spectacles were easy to obtain and should be much more widely used.

The second point was the advantage of admitting even a small amount of daylight and keeping the surroundings light in colour. It was true, as Mr. Chasteney had remarked, that the risk of broken glass had to be taken into account, but in many factories there were openings in the walls and roofs which were not glazed and very often they were blacked out. In his view the admission of some daylight made all the difference to comfort and cheerfulness, and light colouring of as much of the interior as possible was also of the greatest value in the same way.

Commenting on the Regulation which provided for an illumination of 6 ft.c., he pointed out that the committee explicitly stated that in parts of the factory where work was going on 6 ft.c. was not always to be regarded as the minimum required. There were many processes for which a higher or even much higher figure was necessary, but the difficulty had been to include statutory requirements regarding these in Regulations.

Referring to the Ministry of Supply scheme, he said he understood that the Ministry of Supply and other Government supply departments had made out a list of what was called vital factories, presumably large and important establishments, mostly which had direct contracts with the Government Departments, and these factories had been informed that they must provide at once illumination equivalent to that of the I.E.S. code.

But probably, Sir Duncan continued, most national production came from a huge number of smaller factories by way of sub-contracts; at all events a return made a few years ago showed that factories with less than 250 employees were responsible for over half of the production in this country. He could understand that, from the point of view of protection, the vital factories should receive special consideration, but as regards importance of production the two classes seemed on an equal footing.

To have introduced a scheme for bringing about immediate improvement in lighting in all factories engaged on work of national importance would have been impracticable, and it seemed to him reasonable to limit it to the more important vital factories. But these, he understood, were to receive a substantial grant towards the cost of improving lighting. Now, the provision of sufficient and suitable lighting was a legal obligation, and some, if not many, of the vital factories were undoubtedly contravening the Factories Act. In fact, not long ago he was in one of the vital factories and found that, while a new extension was well lighted, the lighting in other parts was disgraceful; the firm, in short, were undoubtedly breaking the law. He confessed it was obscure to him why some firms should receive payment towards

enabling them to carry out their legal obligations while others—in the aggregate just as important—should be left to pay the whole cost out of their own pockets.

Replying to Mr. Cunnington, he said that the points raised had not been overlooked. It was necessary to rely very largely on the lighting engineer who visited a factory to use his own judgment—and experience showed this was a sound judgment. At the same time, in order to secure uniformity of practice as far as possible, a small guide embodying general principles had been prepared by the National Industrial and Electric Lighting Service and was being distributed throughout the country. Any difficulties that might arise would be referred to the Central Committee. This scheme had been devised to help the small employer who was really at a loss to know exactly what to do. It was also available for the use of contractors and those who had to deal with small employers and it was not intended to interfere at all with the usual work of the lighting engineer. The whole object was to obtain the highest standard of lighting in accordance with the Draft Regulations, which had now been issued, and to get conformity with these Regulations as quickly as possible.

Dr. J. W. T. WALSH (*communicated*):—

It is very interesting, in connection with Mr. Weston's remarks on artificial windows, to refer to an investigation carried out by the Illumination Research Committee in 1926-29.*

Clerical work was carried out in a room which could be lighted in any one of four ways, viz., by semi-indirect fittings with vacuum tungsten lamps or with colour-corrected lamps, or by an artificial window using vacuum tungsten lamps or colour-corrected lamps. This "small-scale" experiment was followed by full-scale trials, and these included trials in rooms in which there was mixed artificial lighting and natural light. In these rooms the preference was for artificial daylight from diffusing wall panels, combined with some indirect ceiling fittings (also giving artificial light). In the small-scale experiment, where all natural light was excluded, artificial daylight was preferred to light given by the vacuum lamp, but the evidence as to the advantage of an artificial window over a semi-indirect system was inconclusive.

* Illumination Research Technical Paper No. 10. "The Effect of Distribution and Colour on the Suitability of Lighting for Clerical Work."

Mr. H. C. WESTON, replying to the discussion, said that although he might have given the impression that he was advocating unduly the artificial window form of lighting, frankly he did advocate it and he believed it was likely to be used much more in the future. It had been suggested by Mr. Ackerley that this was a matter for the future rather than the present, but certain objections could be overcome even now. There was no need to use glass, and the opportunity was afforded of exploiting plastics. Moreover, there was no need to use the tubular lamp. If, as had been suggested by Mr. Chasteney, factories were beginning to do without glass altogether, it would be a good thing if one or two units were put in to create the impression of daylight. Apart from this, however, there were many ways in which fittings could be used to produce a more natural appearance in the factory—and that was really the point he was trying to get over.

The difficulty of lighting north-lighted factories had been referred to by Mr. Ackerley, but one method was that to be seen in the E.L.M.A Lecture Hall over the platform, i.e., indirect lighting derived from the illuminated, unglazed roof sections. There was room for a little more imagination on the part of illuminating engineers, especially in dealing with the older factories, and he agreed with Mr. Cunnington that each case should be dealt with on its merits and a system of lighting put in which was best suited to the particular circumstances.

What he meant by factor of safety—mentioned by Mr. Raphael—was that in many cases, in peace time no allowance was made to meet occasional abnormal circumstances, nor even for depreciation, and such installations were now totally inadequate for war-time production. If the I.E.S. Code was adopted, then what he meant by factor of safety was already taken into account, but it was still necessary to allow for the depreciation factor. He had in mind that some provision should be made for expecting the worker to carry on at a very much higher pressure than he was normally expected to do. Even in peace time there were rush orders and the worker was expected to make an unusual effort, but in most cases no sort of allowance was made for that because, normally, the lighting installation was only used for a very short period.

Commenting on the suggestion by Mr. Daniel that the managing director should have the lighting windows and not the factory worker, the author said he would reverse that position entirely. He

recalled a case in which the Directors' room of a large company was indirectly lighted and there was an illumination of 25 ft.c. on the desk of the managing director, who, however, had absolutely no work to do which demanded such good lighting. The workers in the shop, however, certainly had and, therefore, the position which obtained in many cases should be reversed.

Whilst agreeing with Mr. Iliffe that, where possible, it was convenient to have fixed local lighting, he did not think it was always possible to take an average figure for the illumination, because individual requirements varied very widely as, of course, did the nature of the work. In the case of very fine work it would be necessary to have the special spectacles which had been mentioned.

NOTES ON RECENT MEETINGS AND EVENTS

General Meetings in London.

The Society has been fortunate in being able to carry through the initial four meetings arranged to take place in London, in spite of war conditions. In view of the necessary alteration in the time, to 2.30 p.m., good audiences have been obtained.

The opening meeting, on October 8, was held by special permission in the lecture theatre of the Royal Institution (Albemarle-street, London, W.)—a very opportune arrangement in view of the subject of the presidential address ("The Arc as a Standard of Light"), which was illustrated by numerous experiments and heard with great interest. The new President (Professor J. T. MacGregor-Morris) was introduced by Mr. F. C. Smith, to whom a cordial vote of thanks for his great services to the Society during the past year was passed by acclamation. Dr. C. C. Paterson proposed the vote of thanks to the President, who, in responding, referred to the great privilege accorded to the Society in enjoying the hospitality of the Royal Institution.

In the course of the proceedings the Gaster Memorial Premium was awarded to Mr. Dunbar for his contribution entitled "Visual Efficiency in Coloured Light," which appeared in the "Transactions" of the Society for October, 1939.

At the next meeting, on October 22, Mr. H. C. Weston read a paper on "War Time Industrial Lighting." The discussion was opened by Mr. H. E. Chasteney (H.M. Deputy Chief Inspector of Factories), who was followed by Mr. R. Maxted, Mr. R. O. Ackerley, Mr. E. W. Murray, Mr. R. W. Daniel, Mr. A. E. Iliffe, Mr. A. Cunnington, and Mr. F. C. Raphael. Sir Duncan Wilson, by request, reviewed the discussion in a final contribution prior to Mr. Weston's reply.

On December 10 a review of "Effects of Contrast in Illuminating Engineering," illustrated by numerous striking demonstrations, was arranged by Mr. J. M. Waldram, Dr. R. G. Hopkinson, and Mr. W. R. Stevens. Dr. Harper deputised for Dr. Hopkinson, who was, unfortunately, unable to be present A discussion ensued in which Dr. W. D. Wright, Dr. K. Norden, Mr. L. G. Applebee, Dr. J. W. T. Walsh, Mr. J. S. Dow, and Mr. A. Mansell took part. The opportunity was taken by Mr. Percy Good to present a report on "War Time Street Lighting and Aids to Movements in Streets," prepared for the Joint Committee of the Ministry of Home Security and the Illuminating Engineering Society, the discussion of which was deferred until the following meeting.

On January 11 Dr. W. D. Wright read a paper, "The Fundamental Principles of Vision in Very Weak Light," and a brief reference to the report, mentioned above, was made by Mr. J. S. Dow, who arranged demonstrations illustrating some of its main conclusions. In the subsequent discussion Mr. K. J. F. Craik, Dr. J. W. T. Walsh, Mr. P. Good, Mr. J. H. Nelson, Mr. L. T. Minchin, Mr. J. M. Waldram, Mr. C. E. Greenslade, and Dr. K. Norden took part.

Votes of thanks to the authors of papers on these three occasions were put to the meetings by the President, who also made reference to the advantage to the Society of holding such meetings in the lecture theatre of the E.L.M.A. Lighting Service Bureau, whose facilities for demonstrations had proved extremely helpful.

[*We hope to review recent meetings in Local Centres in the next issue of "The Transactions."*—Ed.]

Spring Binders for "Transactions."

Members will receive, with the present issue of the "Transactions," the Synopsis of Contents and Index relating to the previous year (1940). Spring binders, adapted to contain complete series of the "Transactions," are obtainable by members at the price of three shillings and sixpence (price to non-members, four shillings and sixpence).

I.E.S. FELLOWSHIP.

In addition to the list of Fellows which appeared in "The Transactions" for July, 1940 (page 88), the following have since been elected:—

Allderidge, C. J. .....10, Boscobel Road, WALSALL.
Bright, H. .....5, Bloomsbury Square, LONDON, W.C.1.
Catten, T. .....98, Thistledene, Hampton Court Way, East Molesey, SURREY.
Caunt, C. S. .....62, Thackerays Lane, Woodthorpe, NOTTINGHAM.
Cocksedge, F. M. .....Maryfield, Osborne Road, Potters Bar, MIDDX.
Daniel, R. W. .....Bermays, The Park, Gt. Bookham, SURREY.
Gostt, A. W. .....61, Lonsdale Drive, Enfield West, MIDDX.
Head, O. W. .....3, Bernard Avenue, West Ealing, LONDON, W.13.
Horsfall, A. V. .....7, Baronsmede Court, Ealing, LONDON, W.5.
Lewzey, L. G. .....32, Battledean Road, Highbury, LONDON, N.5.
Middleton, F. F. .....Caynton, Foley Road, Redmore, STOURBRIDGE.
Nisbet, Thos. .....“Eildon,” West Brae Road, NEWTON MEARNS.
Norden, K. .....10, Westbourne Crescent, LONDON, W.2.
Penny, A. G. .....33, Denman Drive, Golders Green, LONDON, N.W.11.
Pyser, M. E. .....Central London Electricity, Ltd., 25, Eccleston Place, Belgravia, LONDON, S.W.1.
Raphael, F. C. .....Napier House, 24-27, High Holborn, LONDON, W.C.1.
Tye, L. M. .....52, Combemartin Road, Southfields, LONDON, S.W.18.
Watson, A. G. .....The Gas Accumulator Co. (U.K.), Ltd., Beacon Works, Brentford, MIDDX.

APPLICATIONS FOR MEMBERSHIP.

In addition to the applications for membership which appeared in “The Transactions” for May 1940 (page 53), some supplementary lists have appeared in “Light and Lighting” (October, page 160; November, page 186; and December, page 204). In order to make the records of membership in “The Transactions” complete, a full list of applications to date (January, 1941) is now presented:—

Elections Pending.

The following were presented for the first time at the meeting on January 14, 1941:—

CORPORATE MEMBERS:—

Frobisher, C. M. .....93, Egerton Road South, Chorlton-cum-Hardy, MANCHESTER, 21.
Hanstock, R. F. .....The Paint Research Station, Waldegrave Road, Teddington, MIDDX.
Koch, H. F. .....115, Parkside Drive, Watford, HERTS.
Pelerin, R. .....60, London Road, Dunton Green, KENT.
Stone, W. H. .....16-17, Hills Terrace, CARDIFF.
Haines, H. R. .....Surveyors' Dept., New Scotland Yard, LONDON, S.W.1.

COUNTRY MEMBER:—

Ellson, W. G. .....29, Clive Street, HEREFORD.

STUDENT MEMBER:—

Bulloch, F. .....9, Quarry Place, Hyde Park, LEEDS, 6.

The names of the following applicants for membership, who have now been formally declared members of the Society, were presented at General Meetings on October 8, October 22, or December 10:—

Elections Completed.

SUSTAINING MEMBER:—

Lee, Beesley and Co., Ltd. .....Queen's Road, COVENTRY.
Representative .....Mr. R. E. Battersby.

CORPORATE MEMBERS:—

Addison, S. .....68, Sandhill Oval, Alwoodley, LEEDS.
Benson, W. A. .....c/o Crompton Parkinson, Ltd., 1-3, Brixton Road, LONDON, S.W.9.
Birch, D. .....47, Vernon Avenue, Handsworth Wood, BIRMINGHAM 20.
Bond, W. A. .....88, Perry Hill Road, Quinton, BIRMINGHAM.
Chasteney, H. E. .....H.M. Deputy Chief Inspector of Factories, Cleland House, Page Street, LONDON, S.W.1.
Craven, J. C. .....5, Broomfield Crescent, LEEDS.
Dainty, J. W. .....111, Butt Lane, Allesley, COVENTRY.
Duncan, N. L. .....Electricity Offices, Dockfield, Shepley, YORKS.
Entwistle, E. F. .....371, Rochdale Old Road, Bury, LANCS.
Fowler, E. A. .....79, Alwoodley Lane, Alwoodley, LEEDS.
Gorringe, R. G. .....7, Cartside Street, MANCHESTER.
Grapes, G. T. .....24, Regent Place, RUGBY.
Gregg, W. .....64, Betley Road, Reddish, Stockport, CHESHIRE.
Hammersley, R. G. ...Electricity Department, Gainsborough, LINCS.
Hull, J. N. .....14, Langton Road, RUGBY.
Hulse, R. .....41, West Hill Road, Kings Norton, BIRMINGHAM.
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In what follows we give a preliminary list of members now serving in the Forces. We should be glad to receive names of any others, including particulars of rank and address, when available.

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Algar, F. X.
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Blackburn, C. H.
Blackburn-Maze, L. N.
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White, E. J.
Whittington, T.
Wilman, D.
Willmer, R. J.
Winstanley, G.
Woodrow, V. H.

NOTICE OF NEXT MEETING IN LONDON

The attention of members is drawn to the **next General Meeting** in London, to take place at the E.L.M.A. Lighting Service Bureau (2, Savoy-hill, W.C.), **at 2.30 p.m.** on **February 11,** when a paper entitled **"The Recognition of Coloured Light Signals"** will be read by Mr. J. G. HOLMES.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—"Trans. Illum. Eng. Soc. (London)."

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WAR TIME STREET LIGHTING AND AIDS TO MOVEMENTS IN STREET

A Study of Fundamental Requirements

(Prepared for the Joint Lighting Committee of the Ministry of Home Security and the Illuminating Engineering Society. Presented on Tuesday, December 10th 1940.)

SYNOPSIS

In this study the fundamental conditions underlying "twilight vision" are analysed, and the application of a knowledge of these factors to war-time street lighting is discussed.

The condition of the eye when exposed to very weak illuminations is very different from that prevailing in daylight. In its dark-adapted state the eye is highly sensitive to weak light. The central region of the retina is, however, relatively insensitive, so that small and distant objects are seen with difficulty. Time is necessary for this state of dark adaptation to be attained. Therefore an interval should be allowed when a person is proceeding from brightness indoors into the external darkness. The condition of sensitiveness is easily impaired by exposure to bright light. Therefore definite limits should be set to the brightness of objects in the streets. Visibility of objects which it is desirable to perceive or avoid depends largely on the contrast between their brightness and that of the surroundings. Hence the expediency of the judicious use of white paint; especially if applied to vertical surfaces. Even the weak degree of general illumination afforded by war-time street lighting is extremely valuable, both in enabling persons to see objects in their vicinity and in creating a sense of distance and perspective. Under certain conditions this illumination might, however, be advantageously supplemented by somewhat higher local illuminations at points of importance.

This study is concerned with the behaviour of the eye at very low illuminations, on which any effort to satisfy the needs of "the man in the street" during the night time is necessarily based.

The human eye is capable of adjusting itself to very wide variations in degrees of brightness. The illumination received from summer sunlight on a clear day may attain 10,000 ft.c., whilst the value derived from faint starlight may be of the order of 1/10,000th ft.c.—a range of about one hundred millions to one. The brightness of objects viewed by the eye undergoes correspondingly great variations.

This discussion is devoted to vision at the lowest levels in this range of illumination which in practice is all that is available out of doors on a clear moonless night and is of the same order as that furnished by war-time street lighting.

Behaviour of the Eye in Weak Light.

The behaviour of the human eye, operating at low illuminations of the order of a thousandth of a foot-candle, affords a natural starting point for this investigation. The conditions characteristic of "scotopic" or "twilight" vision are familiar to psysiologists. These may be broadly summarised as follows:—

(1) The condition of complete dark-adaptation, which enables fullest possible use to be made of the feeble light afforded, is only slowly attained by an eye previously adapted to normal illuminations. Certainly in the case of a person emerging from a brightly lighted room into a dark street some minutes must elapse before the eye can "take in" its surroundings with any certainty, and thirty minutes is a reasonable time to allow for full adaptation. Moreover, whilst such adaptation is only gained slowly it can be very quickly destroyed. Momentary exposure of the eye to a bright flash of light, or quite a brief gaze at a surface of normal brightness, will partly undo the results of a long period of waiting. Even apparently normal persons differ much in their speed of adaptation. Some, more particularly elderly people, approach the condition of "night blindness" and always find great difficulty in finding their way in semi-darkness.

(2) Near the centre of the retina is a small depression, the "fovea centralis," where at normal illuminations vision is most acute. It is this area which is normally exercised in the recognition of form. At the low order or brightness characteristics of twilight vision this area is relatively insensitive compared with the surrounding regions. The

same is true, in a somewhat lesser degree, of a larger area, surrounding the fovea, known as the "yellow spot."

In twilight vision two consequences follow:—

(i.) Objects are no longer perceived by direct vision, but "out of the tail of the eye."

(ii.) The outlines of objects are never seen with the same clarity as by normal vision; they tend to appear as masses, limits of which are less clearly defined.

(3) At the low order of illumination characteristic of twilight vision colours can no longer be distinguished. In Sir William Abney's classic experiments it was found that the perception of the colour of spectrum yellow ceased at an illumination somewhat under 0.002 ft.c., though the limit is lower for green or blue light. It may safely be inferred that the colour-sense has been so weakened as to become practically inoperative at illuminations of the order of thousandths of a foot-candle.

Visual Sensitivity at Low Levels of Illumination.

Consideration in turn of these three characteristics of the dark adapted eye leads us to a number of general principles on the observance of which visual sensitivity depends.

State of Adaptation.

It is evident, in the first place, that the provision of even a weak degree of general illumination helps to shorten the period of adaptation and renders the change in condition of the eye less extreme. It also serves a beneficial purpose in fixing the order of brightness to which the eye must adjust itself, and, in this respect, has a certain stabilising influence. It is common experience that the eye, when adapted to full daylight, is in a very steady condition, and only the sudden appearance of an object of surpassing brightness can materially disturb its powers of perception. At the other extreme we have the state of complete dark adaptation, attained by the eye after prolonged experience of complete darkness, leading to extreme sensitiveness. The display of even the faintest light may then disturb the condition of the eye and impair its power of perception. When exposed to a certain illumination—even if only of a low order—the hyper-sensitiveness of the eye is less marked and the effect of exposure to an object of moderate brightness less severe.

From (1) it may be concluded that the first essential is to abstain from any action liable to impair sensitiveness of the retina. By this is meant not merely that extreme conditions of dazzle creating momentary semi-blindness must be avoided. It is also necessary to avoid any condition of excessive contrast such as may depress the action of the eye and prevent it getting the full value of the weak illumination available.

The eye should, therefore, be "nursed" during its passage from normal brightness to comparative obscurity, and care should be taken to ensure, so far as possible, the absence from the field of view of any objects of undue brightness such as exercise a depressing effect on vision.

Limits to Brightness.

As a guide in connection with this problem new standards are necessary. Some indication of the conditions desirable at normal illuminations, say, about .5 ft.c., is afforded by the familiar recommendations that within the direct range of vision (a) the brightness of no object should exceed 5 candles per square inch, and that (b) the variation in brightness of objects within this range should not exceed 100:1.

There is ground for the belief that as the general range of brightness rises the absolute limit to brightness may also be increased, whilst the limiting ratio requires some reduction. The tendency for these two factors would presumably be in the opposite direction when very low orders of brightness are concerned. As, however, there is little positive information available on this point, we might, as a first approximation, apply the above rules to conditions met with in areas receiving an illumination of 0.0002 ft.c. Application of the rule quoted above would then give a limiting brightness of 0.0002 candles per square inch, roughly equivalent to 0.1 equivalent foot-candles. Adoption of the 100 to 1 ratio, on the other hand, would give a brightness of about one-fifth of this, namely 0.02 e.f.c.*

Size of Object.

Under the conditions affecting the powers of perception of the eyes at this very low level of illumination, the central region of the eye, the "yellow spot," where perception of form is mainly accomplished at normal illuminations, is relatively insensitive. Seeing is effected by the peripheral region of the retina, where perception of form is less acute. It cannot, therefore, readily recognise details nor distinguish objects at a distance, and can only see the broad shapes of things at close quarters. For one thing, the image of an object subtending at the eye angle less than 2 to 3 degrees is liable to fall inside the yellow

* In giving these values it is assumed that the bright object is located with the street as a background. With brighter backgrounds different conditions would apply.

spot, when it becomes invisible. Objects of this size cannot be seen with certainty. They " appear and disappear " as one is looking at them.

Another closely related factor is the association of size and brightness. At normal illuminations two objects of the same physical brightness, but differing in area, still have the same brightness. Under a given illumination a half crown is no brighter than a threepenny bit. But at very weak illuminations this is not necessarily the case. Impressions may depend upon the product of area and brightness. Larger objects appear brighter than small ones, which again enhances their visibility.

Importance of Contrast.

Another factor of vital importance is the ratio of brightness between object and its background. At high illuminations, under very favourable conditions, a difference in brightness of only one to two per cent. can be detected. It may be doubted whether, under such conditions as we are considering, a difference of 20 or even 30 per cent. can be detected with certainty—for example, an object of quite substantial size which reflects only 20 per cent. less or more than the adjacent roadway and receives an illumination of only 0.0002 ft.c. might quite easily escape recognition.

In order to ensure that an object may be visible to people in the street at a certain distance it is therefore expedient (i) to ensure, if possible, that the angle subtended at the eye is well outside 3 degrees; (ii.) to secure a relatively high contrast with its background, and at the same time (iii.) to guard against the possibility of depressing vision by *excessive contrast*, so great as to approach glare conditions, such as arises when objects of relatively high brightness are within the field of view.

Loss of Light by Imperfect Transmission of Reflection.

When the amount of light available is relatively small the importance of avoiding casual losses is correspondingly great. A loss, through deterioration in transmission or reflection, of, say, 10 or 20 per cent., has a much more serious effect on vision and on amenities generally than would be the case when the illumination and the resultant brightness are relatively high. Not only, therefore, should lighting appliances, such as those used for street lighting, be maintained in good condition, but care should be devoted to all relevant factors such as the cleanliness of windscreens of motor vehicles, to the upkeep of surfaces treated with white paint, etc., in order to render them more visible by night.

Colour.

There remains the question of colour, referred to under (3) above. Under this heading there is not a great deal to be said, except to recall the practical consequences of the physiological phenomena mentioned. One obvious conclusion is that it is of no use, at a very low order of brightness, to rely on colour as a means of distinction, since colour as such can no longer be distinguished. It is also well to recall the rapid loss in sensitiveness to red at weak illuminations—with the result that a red object, such as a pillar box, becomes in effect black and indistinguishable from a dark background. Objects desired to stand out from their dark surroundings at low illuminations, and which are identified by their colour under normal conditions, should preferably be painted green or blue. Whilst the sensitiveness of the eye to blue light is accentuated at very low illuminations, experience has shown that the use of such light, in preference to white light, is not advantageous. The general use of pure blue light involves considerable absorption, and is therefore uneconomical, and for some purposes it is considered inexpedient owing to certain loss in sharpness of outline of objects illuminated when viewed from some little distance away.

Applications.

In what follows an attempt will be made to apply some of the principles outlined above to conditions such as are experienced on dark nights, and in particular to war-time street lighting, which furnishes an illumination of the order of 0.0002 ft.c.

It has been pointed out that the utility of this low order of illumination depends entirely on the avoidance of factors liable to depress visual sensitivity. As a first step it is desirable to do everything possible to facilitate the transition from the brightness indoors to the relative obscurity outside.

Light traps, besides their primary object of preventing escape of light from within, have a secondary field of utility—in providing a period of adaptation. If there were a general understanding that behind each entrance of the street there should be a short passage or ante-room where the illumination was graduated by steps from the full illumination inside (say, 3-5 ft.c.) down to, say, 0.02 ft.c. at the threshold where, if possible, they should linger for a short time, the final transition down to 1/10,000th or less of the original illumination would be rendered easier and

the period of subsequent adaptation shortened. In any case, a wait of a few minutes is desirable before movement is made.

The next step is to avoid the presence of objects of undue brightness out of doors. Here we encounter the familiar difficulty that the requirements of different classes of users may not be the same. Conditions which satisfy the needs of persons on foot may also prove of some benefit to drivers of motor vehicles. But the latter have other requirements—based mainly on their need to see objects at greater distances. Headlights and traffic control signals, the power of which is necessarily fixed at a value far exceeding that necessary for the recognition of objects at short range, inevitably give rise to some degree of glare. In both cases, however, control of the beam and the adoption of screens and masks does much to mitigate the trouble. It is chiefly when regulations are disregarded that serious glare is liable to arise.

Seeing that "brightness" is a fundamental characteristic of all forms of direction and display signs and other objects designed to attract attention, there is an evident need for simple "brightness-meters" adapted to the testing of these exceptionally low values. The absence, until recently, of such devices (now specified in BS/ARP. 30) goes far to explain the tendency for specified values to be exceeded in practice.

Objects of "Undue Brightness."

For all classes of users, however, the presence of unduly bright objects in the field of view is a drawback. Indications of limiting brightness have been quoted above. It is no doubt arguable that at this low level of illumination considerably higher values might be permitted without detriment to vision. It is, however, interesting to observe that the first of these values (0.1 e.f.c.) is the maximum assigned to illuminated A.R.P. signs (BS/ARP 32) as a result of long and continued and careful experimental investigation, whilst the second is exactly that specified in the Lighting Restriction Order as the limiting brightness of illuminated display signs. Hence there seems good ground for the adoption of a value of brightness of the order of *0.05 to 0.1 e.f.c.* as a limit in streets—especially as these limits have been independently determined with a view to restricting conspicuousness from the air.

It may be useful to apply this yardstock to luminous objects commonly met with in streets. Reference has been made above to motor car *headlights* and *luminous traffic signals*. The position in regard to *rearlights* and *side lights* is possibly somewhat different. Their effectiveness is properly defined in terms of *brightness* limited by the use of suitable diffusing media. Other devices, such as the use of a concealed light under the body of the car showing its breadth by silhouette or the application of indirect lighting to the back surfaces of cars, might well be explored and the liability to glare diminished.

Lights indicating the positions of *refuges and obstructions* frequently offend by their glare, making it difficult to distinguish outlines of adjacent objects. The Restrictions on Lighting Order No. 74, 1940, specifies a brightness for the "cross" of 0.5 candles per square ft. (roughly 1.5 e.f.c.), which is fifteen times the extreme limit proposed above. (Experience suggests that this value is often greatly exceeded.) The same applies to red lights indicating obstructions. The limitation to 1 c.p. (probably also little observed in practice) is not accompanied by any restriction in brightness, and the presence of such lights may actually impede observation of the limits of the obstruction. From a visual standpoint requirements would be better met by ensuring that objects are provided with a low illumination enabling them to be recognisable and that the brightness of any signal light, intended to give warning at a distance, does not exceed the limits specified above.

Regarded from this standpoint the *torches* commonly used by pedestrians have likewise great drawbacks. The concentrated beam they provide produces an illumination at once uneven and in excess of that needful. The disabilities that arise from their shining direct into the eyes of persons approaching and so destroying dark adaptation for some considerable time, have been the subject of frequent comment. Torches would be more serviceable if constructed in a box form with no lens but a light-giving area of several square inches giving diffused light of low brightness but even quality, and equipped with a hood in order to render the emission of light above the horizontal improbable, if ordinary care is exercised.

Application of Theory to Size and Contrast of Objects in Streets.

The theory outlined under these headings has an obvious bearing on road amenities and safety. Under conditions of twilight vision many assumptions commonly made in regard to safety of traffic no longer apply. It has been shown that a degree of contrast much beyond that ordinarily sufficient may be

necessary in order to enable even objects of substantial size to be seen. The images of objects subtending less than about 3° at the eye are liable to be received on the insensitive area and escape notice. Now 3° represents about 2½ ft. at a distance of 60 ft. It is, therefore, expedient that obstructions should be illuminated over an area having at least this linear dimension. This sets a new limit to the distance at which objects are visible. The study of these conditions should therefore form an essential part of any scientific enquiry into the origin and avoidance of traffic fatalities.

At the value of illumination prescribed for war-time street lighting it is desirable to increase the available *brightness* whenever it is expedient to do so. By selecting *materials of high reflecting power* we may sometimes achieve results as good as if ten times the illumination on a relatively dark material were provided.

The area of darkest tone commonly met with in the street is the road surface. A city pavement, in general, comes conveniently about mid-way between this and white paint, and therefore affords a moderately good background both for the figures of persons in dark clothing and for obstacles treated with this material. White paint used with discretion at *busy crossings* enables persons crossing the roadway to be more easily seen. It is evident, however, that this treatment could not be applied on a large scale to road surfaces and pavements. Otherwise we should be providing conditions equivalent to an illumination perhaps ten times as great as the minimum sanctioned.

On *vertical surfaces* such as walls and railings, etc., the advantages of white or light grey have been obvious. The extensive whitening of the kerb both on the horizontal and for drivers of vehicles and persons on the other side of the road, the value of the whitening of the *vertical surfaces of kerbs* has proved itself.

The application of white paint to motor vehicles is similarly useful, but in order to get the full value of this device it is expedient that it should be applied to a much greater area than is at present usual.

Besides the primary need of observing relatively big objects, e.g., bodies of persons at close quarters so as to avoid collision, contrasts in brightness play an important part in creating a sense of perspective and enabling people to "size up" their position. Occasional lightening of familiar objects, such as the outlines of entrances to buildings, so that they "show up," is helpful in this respect.

This particular aspect is also of interest to a driver who relies on perspective in order to judge his position relatively to a distant vehicles. It has been remarked that, even at normal levels of illumination, completely even illumination of the highway alone is not a satisfactory solution. A motorist proceeding at high speed down a roadway so lighted is liable to lose all sense of speed and position. It is only the recognition of passing objects at the roadside that preserves this sense. This is illustrated by the admitted value under conditions of war-time street lighting of the circular white rings on tree trunks, a useful device, consistent with the theory here advanced.

On the other hand, *isolated bright spots of light*, such as the luminous crosses on islands (and, in some cases, the rear lights of motor vehicles), may, unless carefully controlled, have precisely the opposite effect—they destroy perspective and may render it most difficult for the user of the roadway to see what is beyond them.

In view of the fact that only very weak illumination is provided on certain roadways, and that the vast majority are at present provided with no artificial lighting, there seems every reason to exploit to the full the revealing value of white surfaces placed at corners and similar devices which show up in a headlight beam. Wider use might also be made of *directive reflecting surfaces*, as commonly used for warning signs, etc.

It has sometimes been suggested that the escape of a small amount of light at angles very slightly below the horizontal is a valuable feature of war-time street lighting units, because it enables the sources to serve as beacons, marking out the way. Theory, however, would indicate that for the ordinary user of the roadway the comparatively high brightness of such visible light would tend in some degree to depress vision—at least in the case of sources mounted at the lower levels (10 and 15 ft.). There is perhaps more force in the suggestion from the standpoint of the driver of a motor vehicle who has a bright light from his headlamps. Yet it would seem that, even in this case, the need might be more readily met by other means.

Controlled Local Brightness.

There have been suggestions in regard to various forms of local lighting (for example, restricted beams of light at comparatively high levels of intensity at crossings, etc.) as an alleviation of the "black out." Whilst such devices may have a certain value as supplements to the existing system of war-time street

lighting, they scarcely offer a satisfactory alternative, and may more easily determine disabilities. Experience seems to have proved the fundamental soundness of the belief that the groundwork of any effort to improve amenities in darkened streets must be the provision of a *uniform level of illumination* with, so far as possible, no regions of complete darkness, and if necessary with some regions slightly higher than others. The impression produced when war-time street lighting is applied uniformly over a large area is so much stronger than that of a few units in a single street.

There can be no question but that the measure of illumination such as is provided by war-time street lighting, though so small, is of appreciable benefit, especially when applied on a large scale. It affords a ground work on which the eye can build up impressions from any extra casual light it may receive, much more successfully than if they occurred in total darkness.

It would, however, add to amenities in the streets if somewhat *higher illuminations*, under proper control, or suitably screened, could be adopted *locally* in certain instances. Although the aid obtainable from the contrast is substantial, there are limits to the possible gain. The darkest material likely to be available would hardly reflect less light than 5 per cent., and the lightest, such as white paint, not more than about 80 per cent. In so far, therefore, as one relies on difference in reflecting power to produce contrast the maximum possible ratio in brightness is about 15 : 1. If the ratio is increased beyond these limits, as, for example, by using self-luminous objects (such as signs illuminated within), a further gain in visibility is possible—especially for the more distant objects, until we approach a point, probably well above the value of 0.1 e.f.c. noted previously, where the brightness begins to interfere with the state of dark adaptation of the eye and to depress the level of visibility of surrounding areas.

Various applications of this principle could be suggested.

Presentation of Report on War-time Street Lighting.

At the meeting of the Society held on Tuesday, December 10, 1940, this Report was formally presented by Mr. Percy Good, who explained that it had been prepared for the Joint Lighting Committee of the Ministry of Home Security and the Illuminating Engineering Society. It was not the intention to discuss the Report at this meeting but, in order to secure its publication, the Council had agreed that it should formally be presented now and should come forward for discussion at a later date.

Mr. Good remarked that a large number of decisions with regard to street lighting under blackout conditions had been made quickly by the authorities immediately concerned. Many questions had necessarily had to be dealt with from the point of view of expediency and of providing facilities for doing something at once rather than from the point of view of basic principles. Moreover, there was wanting a full knowledge of the fundamentals which governed lighting in connection with these very low levels—which were requisite for the conditions of a policy which dictated blackout as being more or less the order of the day. It was unfortunate that before any attempt was made to determine A.R.P. lighting, a review of the fundamental principles of seeing under these conditions was not made and published. That would undoubtedly have altered a number of things that had already been done. The Joint Committee, therefore, decided to appoint a small committee to draft a memorandum on the fundamental requirements, which he was now presenting. He added that the basis of the document was due to the Hon. Secretary of the Society—Mr. Dow—as he made the first draft. Subsequently, Dr. Walsh, Dr. Stiles, and Mr. F. C. Smith (the immediate Past-President), and himself had made some observations on it with a view to checking conclusions and presenting it in the form most acceptable to the man in the street. He hoped that it would lead to an interesting discussion. Personally, he hoped that it would lead, as time went on, to a very great improvement in the methods and aids to movement during such time as it was necessary to continue under complete blackout conditions.

The HON. SECRETARY mentioned that the discussion of this Report would take place at the next meeting of the Society on January 14. The Report would appear in "The Transactions" in due course.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—"Trans. Illum. Eng. Soc. (London)."

THE FUNDAMENTAL PRINCIPLES OF VISION IN VERY WEAK LIGHT

By W. D. WRIGHT, A.R.C.S., D.Sc. *(Member)*

(Paper read on Tuesday, January 14th, 1941, at 2.30 p.m.)

SUMMARY.

A scale of subjective brightness is proposed in terms of which the changes in sensitivity of the eye can be recorded. The unit of subjective brightness is called a "brill," and it is suggested that the scale may also prove satisfactory as a means of specifying contrast. An experiment is described which enables the changes taking place during dark adaptation to be appreciated in a very striking manner and by means of which the time required to adapt down to low levels of adaptation other than complete dark adaptation can be recorded. The effect of area on visibility is briefly discussed and the action of a glare source in depressing the sensitivity of the eye and delaying its recovery is described. A short discussion of the extent to which contrast is affected by a reduction both of illumination and of area follows, after which a new test for defective night vision is described and some preliminary results reported. In the final section a brief description of a portable binocular matcher that can be used as a "brillmeter" to measure subjective brightness is given.

Introduction.

It is all too obvious that the subject of vision in very weak light is of vital interest to us at the present time, but although to write about a matter of such immediate concern has its advantages, there is the disadvantage that so much has already been said that there seems little to add to the discussion. For this reason no apology is necessary for an approach to the subject from an angle that appeals to the author very strongly, namely, that of subjective brightness. In doing so, he may, perhaps, expose himself to the criticism that a "red herring" is being introduced into a subject that is already sufficiently complicated for most of us. Against this, it may be argued that what novelty there is in the method should prove stimulating and may lead to fresh ideas, but it is the author's belief that many, although not all, of the problems of low-intensity vision are best examined as problems of subjective brightness.

A Scale of Subjective Brightness.

The apparent or subjective brightness of a surface is governed by two factors—the amount of light radiated from the surface and the sensitivity of the eye under the conditions in which the surface is seen. The sensitivity of the eye is controlled in part by the effects of contrast from other regions in the field of view, but mainly by the state of adaptation of the eye, so much so, that a source of light may appear glaring to the dark-adapted eye but quite dull to the light-adapted eye. These changes in sensitivity are largely the result of changes in the concentration of the photo-chemical substances in the retina, these substances, visual purple in particular, being decomposed by light but regenerated in the dark.

The usual means of specifying the sensitivity of the eye is to determine the threshold brightness of a surface when it can just be seen. Such results are sometimes directly applicable to particular problems of lighting; sometimes they are not. Further, it does not necessarily follow that deductions based on threshold measurements can be legitimately applied to brightness above the threshold. It may happen, therefore, that it would at times be better to describe the changes of visual sensitivity in terms of apparent brightness rather than of thresholds; examples, where this arises, are mentioned later, and the references made to apparent brightness and to contrast in the recent report on "War-time Street Lighting"(1) may also be quoted. Should it be desired, however, to refer to definite magnitudes of subjective brightness, the very real difficulty that no scale is in existence is at once encountered.

Although photometry is already overburdened with units and definitions, and in spite of the fact that apparent brightness cannot be measured with any degree of accuracy, the need for a scale seems sufficiently evident to outweigh these considerations. It is therefore suggested that a scale as defined below should be adopted:—

When an extended surface of physical brightness B is viewed by a dark-adapted observer using both his eyes, then the apparent or subjective brightness A should be calculated from the equation

$$A = 10 \log_{10} (B+1).$$

The unit of apparent brightness may be called a "brill," and A will be expressed in brills when the unit of B is 10^{-3} e.f.c.

Before attempting to justify the scale, it will be

convenient to have some idea of the magnitudes that it yields. These are shown in Table 1, in which the

Table I.

THE APPARENT BRIGHTNESS EXPRESSED IN BRILLS FOR A SERIES OF PHYSICAL BRIGHTNESSES AS SEEN BY THE DARK-ADAPTED OBSERVER.

Physical Brightness.	*Apparent Brightness.*
0.00001 e.f.c.	0.04 brills
0.0001 „	0.4 „
0.001 „	3.0 „
0.01 „	10.4 „
0.1 „	20.0 „
1.0 „	30.0 „
10.0 „	40.0 „
100.0 „	50.0 „

apparent brightness expressed in brills has been worked out for a series of physical brightnesses as seen by the dark-adapted observer. The following examples will also help to visualise the scale:—

A road surface with a reflection factor of 0.2 will have an apparent brightness of 0.17 brills when seen by the dark-adapted observer under the black-out illumination of 0.0002 ft.c.

A concrete road surface under the light of the full moon has an apparent brightness of about 2.5 brills to an observer who has become adapted to the moonlight after a few minutes.

To the "moonlight-adapted" observer, the surface of the full moon itself probably has an average apparent brightness of about 55 brills.

With regard to the specification of the scale, the condition of dark-adaptation has been chosen in view of the fact that the scale would be especially useful for low-intensity work. Since all values of subjective brightness can be aroused in the dark-adapted eye, there is no theoretical reason why a scale for any other adaptation level need be provided. In practice, however, an alternative or sub-standard scale at a higher adaptation level may prove convenient, but that can be left to the future. So far as the observer using both eyes is concerned, there are sound theoretical reasons why the unit should be based on monocular vision, using a small artificial pupil to restrict the cone of light entering the eye, but these are discounted in favour of the practical advantage of a specification for an observer unencumbered by any gadgets in front of his eyes. The duration of the dark-adaptation need not exceed thirty minutes, and a shorter period may prove adequate.

The relation between A and B should be so chosen that the figure for apparent brightness bears at least some relation to what we think we see. Unfortunately, there is little data available that can be used to determine this relation, and in any case the measurement of sensations is so doubtful a process that it would be futile to spend a long time trying to satisfy some mythical condition. There is, however, some evidence ([2, 3, 4]) which shows quite definitely that at low intensities we need a greater relative change of intensity to produce a given change in apparent brightness than we do at high intensities. That this condition is generally satisfied by the definition of A is evident from Fig. 1, in which the data

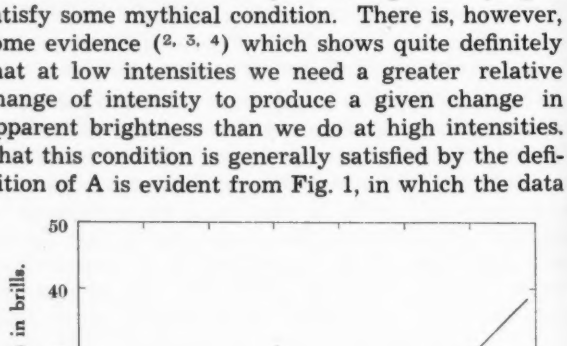

Fig. 1. Relation between the apparent brightness in brills and the physical brightness in e.f.c. for the dark-adapted observer.

of Table 1 are shown graphically. The upper part of the curve is linear, in accordance with the known constancy of $\frac{\Delta B}{B}$ at high intensities; at low intensities the curve flattens out in agreement with the data, for example, of Abribat ([4]), while so far as could be judged from some contrast experiments on the dark-adapted eye, the heel of the curve is located more or less correctly. In addition to giving the curve the shape required, the 1 in the (B + 1) term also ensures that for small values of B the curve approaches to zero but never becomes negative. It must be emphasised, however, that the only use to which the proposed scale can, strictly, be applied is to provide a means of *identifying* subjective brightness values. Later, it is assumed that a given difference of brills corresponds to a given contrast, but this is more in the nature of an act of faith than anything else.

For physical brightnesses greater than about 0.01 e.f.c., the formula becomes effectively

$$A = 10 \log_{10} B.$$

At very high values of B a saturation effect occurs

([5]), so that further increases in B cause little further gain in apparent brightness. This stage is not represented by the scale, but it occurs in a brightness region that is of no practical interest to illuminating engineers.

The particular choice of unit is quite arbitrary, since it would make no difference to the utility of the scale if the unit were increased or decreased by a factor, say, of 10. The choice that has been made seems reasonable to the extent that surfaces with an apparent brightness of less than 1 brill are distinctly faint, while those with a value greater than 10 brills are quite bright. The name of the unit is, of course, based on the fact that apparent brightness is closely associated with what is ordinarily understood by brilliance.

The reference in the definition to an extended surface is not unimportant. It is well known that the value of the threshold intensity is a function of the size of the test field, and in the same way the apparent brightness of a surface increases with area for low brightness values. For the purposes of the definition an extended surface may be taken as one subtending at least 10° at the eye.

The author has recently developed a portable binocular matcher that can, under some conditions, be used as a " brillmeter." To avoid any interruption to the main topic of the paper the brief description of the device is deferred to the final section.

Dark Adaptation.

The process of dark adaptation is well understood in a general way. We know that the longer we stay in the dark, the greater the concentration of visual purple in the retina, the higher the sensitivity of the eye. The rods overtake the cones in sensitivity, the fovea becomes the least sensitive part of the retina, and if we record the amount of light required to make a given surface just visible, its magnitude steadily diminishes. This action continues for a long time, although after half an hour its rate of progress slows up very considerably.

Yet a record of dark adaptation in these terms does not tell the full story, especially for the purposes of illuminating engineers, who rarely have to deal with the complete absence of light. There is a simple experiment which anyone can carry out and which helps very much towards the better understanding of the practical consequences of dark adaptation. The experiment is merely this: Bandage one eye, say the left, for 30 minutes, excluding all light from it, and leave the right eye exposed to the prevailing illumination in the room, which, in the particular example to be described, was of the order of 5 ft.c. At the end of the 30 minutes, go outdoors into the dark, undo the bandage, and then compare the vision of the right and left eyes during the next 20 minutes by alternately opening and closing the eyes. The results of the author's observations on a clear, starlit night, with no moon, were as follows:—

> The left eye was immediately able to see very clearly the objects in the garden, the trees silhouetted sharply against the sky, the sky itself a fairly light background. No noticeable change was observed with the left eye vision, and it may safely be assumed that it became adapted to the starlight after a very short time. With the right eye, however, everything appeared very dark, practically nothing could be seen of the trees against the sky nor of the objects in the garden. Gradually the sensitivity of the eye increased, the sky became lighter, the trees began to show up. Tests with neutral filters showed that after 4 minutes the sky appeared as bright to the right eye as it did to the left with a filter of density 0.6 placed in front of it. After 8 minutes, only a 0.3 filter was required, and in 10 minutes the sky was equally bright for both left and right eyes. But it was not true to say that vision was equally good in both eyes. Although the sky was as bright, the branches of the trees were not as dark for the right eye as for the left. Partly as a result of after-images, and partly due to a general turbulence in the retina, there appeared to be a light haze spread over the field of view. This was present at 4 minutes, 8 minutes, 10 minutes, and had hardly disappeared at 15 minutes. The effect was to reduce very greatly the contrast of the trees against the sky, and whether for this or other reasons the definition was also poor. The result might be described rather crudely by saying that after 10 minutes the eye had become fully sensitive to light, but required 15 minutes to become fully sensitive to the absence of light.

This experiment is worthy of detailed discussion. First, anyone repeating this experiment may find that the times as given above may not agree exactly with his own. That is very possible, as the period of adaptation does vary from individual to individual. Except in abnormal cases, however, the general features of the experiment should be repeated satisfactorily. Next, to what extent does this experiment conflict with the record of the dark-

adaptation process as determined by other methods? For example, threshold measurements or measurements of subjective brightness? As the sensitivity of the eye increases, the threshold brightness will diminish, but the presence of the physiological haze in the retina will act in the opposite direction and make the threshold value higher than it would otherwise be. On the other hand, the subjective brightness of a patch of light well above the threshold, will increase in magnitude as the sensitivity of the eye increases, but the haze will now work in the same direction and make the sensitivity apparently too high. Neither method, therefore, gives a true picture of the way vision improves during dark adaptation.

Before considering the practical consequences of these phenomena, it is worth noting that this experiment can be used for a measurement that is otherwise rather awkward, namely the determination of the time required to adapt from one level to another. By taking advantage of the fact that the eye becomes light-adapted more quickly than it becomes dark-adapted, it is possible, for instance, to find the time required for the eye to adapt from an illumination of 5 ft.c. to that of the light of the full moon. The dark-adapted left eye will quickly adjust itself to the moonlight; it is therefore only necessary to note the time required for the vision between the left eye and the light-adapted right eye to become effectively the same. In the author's own case, a period of only five minutes was found.

Perhaps the most important deductions that follow from the phenomena just described are the many advantages that are derived from even a small amount of light. It is true that when some light is provided, the eye will not assume the super-sensitive state of dark adaptation, yet the sensitivity of the eye for all but the very faintest objects will be hardly affected. On the other hand, objects within the range of the light source will be better illuminated, and therefore more easily seen, the time for the eye to adapt is reduced, and the eye is generally in a more stable state than if it were completely dark-adapted. After-images from previous light stimulation, light patches from pressure on the eyeball due to rubbing the eyes or from blinking, and the self-light of the retina all have a relatively greater effect when the eye is completely in the dark. Again, small faint objects are always liable to vanish if they happen accidentally to be imaged on the fovea. Quite a small amount of light will help to overcome this instability, and is advantageous for this reason alone, apart from the other gains already mentioned.

In the report ([1]) referred to above, the need for some period of adaptation after leaving a lighted room is emphasised. The dimly-lit vestibules that are recommended should prove a great help, especially if the previous illumination has not been too high. This should preferably not exceed 5 ft.c., however attractive a higher level might appear. On a moonlight night, a person can of course step out-of-doors straight away and see without any difficulty. In the same way, a motorist will rapidly become adapted to the light of his headlight, which, with the official mask, may provide an apparent brightness of some 2 brills on a concrete road surface.

Area Effects.

Although there is abundant evidence to show that the amount of light required to make a large object visible is markedly less than that required to reveal a small object, it is by no means easy to establish an exact relation between area and intensity. Probably no such relation can exist, for there are too many variables, especially that of the varying distribution of the rods over the retina, for the relation to be other than empirical. For practical purposes, however, it may be assumed that for objects below 1°, the eye is sensitive to the total amount of light entering the eye, that is to say, threshold brightness × area = constant; for objects between 2° and 7° the relation becomes threshold brightness × $\sqrt{\text{area}}$ = constant, while above 7° the threshold brightness itself approaches constancy ([6, 7]). The fact that the eye tends to respond to the integrated light falling upon it indicates that there is some degree of summation going on in the retina. The physiological basis for this summation has been very effectively demonstrated in some recent experiments by Hartline ([8]). In these, he has recorded the electrical responses along single nerve fibres in the retina of both the frog and the alligator, and has measured the area of the retina over which a tiny spot of light could be moved while still initiating impulses down a single fibre. In this way he has plotted the "receptive fields" for individual fibres and has found that each field has a maximum of sensitivity in the centre of its field, and that the fields for different fibres overlap extensively.

When a small object is viewed, it follows that a comparatively large number of fibres will receive impulses, but the response along each will be weak unless the brightness is increased. For a large

object, on the other hand, the number of fibres stimulated will not have increased in proportion to the area of the image, so that the response along each fibre will be relatively greater and the threshold brightness lower.

Not only is the threshold brightness dependent on area, but the apparent brightness of a surface above the threshold will also be affected, so that a large area will yield a greater number of brills than a small area of the same physical brightness. Observations using the brillmeter showed that the apparent brightness of a surface dropped from 1.1 brills to 0.5 brills as the angular subtense of the surface was reduced from 4° to 1°. This is rather less than might be expected from the corresponding threshold results, but it is generally true that the summation effects in the retina tend to diminish as the amount of light increases.

Apart from the general relation between area and apparent brightness, the local effect arising from the poor sensitivity of the fovea must also be considered. The threshold for the foveal cones is perhaps a thousand times higher than for the extrafoveal rods, so that a small, faint object may sometimes disappear when it happens by chance to be focused on the fovea. The situation is rather different from that of the blind spot, since the blind spots in the two eyes correspond to different parts of the field, whereas the foveae correspond to the same parts. Hence, when the image falls on the fovea of one eye it will also fall on the fovea of the other.

The illuminating engineer is, of course, interested in the size an object should have for its visibility to be an optimum. It is obvious that this must depend on the physical brightness and the conditions of viewing. If the object has not only to be seen but also to be recognised as something, then an angular size of perhaps 5° is necessary, when viewed at the distance at which recognition becomes important. This comparatively large value will evidently only be required when the brightness is of a low order; it will certainly prove advisable for brightnesses of the order of 0.0002 e.f.c.

Glare.

A bright source of light seen against a dark background produces a sensation of glare. This arises through abnormal photo-chemical decomposition in the retina, almost certainly through electrical interaction in the retina producing an inhibitory effect on the response from other parts of the retina, and from the effects of scattered light in the optical system of the eye. The practical consequences of glare have been discussed extensively elsewhere (see, for example ([9, 10])). The two facts of which we must take particular note are that when the eye is working at very low illumination levels the source need be of only small intensity to produce quite serious glare, and that the effects of a glare source are likely to be more serious and more lasting when acting on a fairly completely dark-adapted eye.

The extent to which a glare source makes the surrounding objects blacker depends a great deal on the illumination of these objects. A typical result obtained with the author's colorimeter ([11]) by binocular

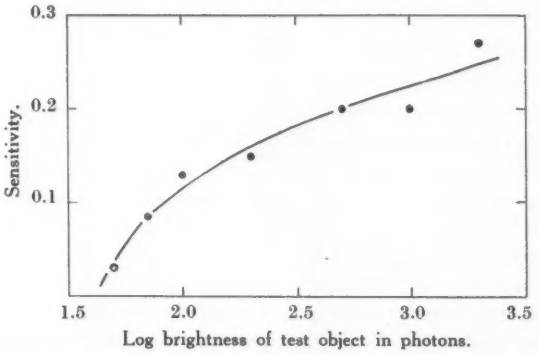

Fig. 2. Variation in the apparent sensitivity of the eye when subjected to glare, as the brightness of the test object is varied.
The sensitivity was measured by dividing the physical brightness required in the left eye to match the test object seen in the right eye after that eye had been subjected to a glare source for 2 secs., by the brightness required to make the match before subjecting the right eye to glare.
The glare was produced by a circular patch of 1° angular subtense, situated 2½° from the test object, and having a retinal brightness of 200,000 photons.

matching is illustrated in Fig. 2. It is apparent that the reduction in brightness of a faint object is many times greater than that for a bright object.

There is no doubt that a considerable fraction of the retina is affected by even a small glare source and that its recovery of sensitivity may take some time. This was demonstrated by Schouten ([12]), and some unpublished results of the author are in general agreement with his. On the other hand, momentary exposure of a glare source produces only momentary loss of sensitivity. This can be very disconcerting and in some cases dangerous, but it would be a mistake to exaggerate the consequences. Only when a glare source is exposed for some five seconds or more is recovery materially delayed, and it may then occupy anything from a few seconds to one or two minutes.

Where permanent lights, such as traffic signals, have to be installed, it would be of great advantage to provide local lighting to fall on the surrounding

objects. The results shown in Fig. 2 demonstrate that the gain in visibility will increase very rapidly the more the illumination rises above the threshold.

Contrast.

If we assume for the moment that the scale of subjective brightness illustrated in Fig. 1 is a true representation of what we see, then we can use it as a means of measuring contrast. The brill scale certainly does not, and never could, provide a means of measuring sensations, but it may be legitimate to use it to measure sensation intervals or contrast. The theoretical difficulties of measuring contrast have been discussed elsewhere ([13, 14]), and so far as the author is aware, these difficulties still exist. But the measurement of contrast may almost be described as an urgent practical problem, whereas the investigation of the exact validity of a contrast scale may take several years. In the meantime, it is suggested that the brill scale be tried as a working scale for the specification of contrast; if practical experience shows that it is unsatisfactory for this purpose, then its use in this way would have to be discontinued. Should this prove necessary the value of the scale for the specification of subjective brightness would be in no way affected.

Qualitatively Fig. 1 undoubtedly represents the change in contrast that takes place as the illumination is reduced. For example, two surfaces which have a brightness ratio of 2 : 1 will possess a contrast of 3 brills if their mean brightness is 10 e.f.c.; when the mean brightness is reduced to 0.01 e.f.c. the contrast falls to 2.7 brills, while at 0.0001 e.f.c. it is reduced to 0.28 brill.

A particular instance of the use to which the scale can be put is in the determination of the upper limit for the brightness of lighted signs in the black-out. In a normal lighting installation it is sometimes recommended that the brightness variation should not exceed 100 : 1. This probably corresponds to a contrast of nearly 20 brills for the observer adapted to the level of the lighting installation. (It would be almost exactly 20 brills if the installation were viewed by a dark-adapted observer.) We may, therefore, conclude that for a person under black-out illumination, the maximum permissible contrast should be 20 brills. As the lowest subjective brightness he will perceive may safely be assumed to be zero, the maximum physical brightness permissible will be that corresponding to a subjective brightness of 20 brills in Fig. 1, namely, 0.1 e.f.c.

Just as the reduction of the area of a surface lowers its apparent brightness, so the contrast between two surfaces is reduced. If the mean apparent brightness of the two surfaces were known for different areas of the surfaces, then a rough guide to the change in contrast with area could probably be deduced by comparing the slope of the brill curve at each of the apparent brightness values. Referring to the experiment already reported on the effect of the change of area from 4° to 1°, suppose in each case the area were divided in two, one-half being 20 per cent. brighter than the other. The apparent brightness of the larger area was found as 1.1 brills, and at this point, on the curve in Fig. 1, a 20 per cent. change in physical brightness corresponds to a brill change of 0.19. For the smaller area the apparent brightness was 0.5 brill, and here a 20 per cent. change in physical brightness corresponds to a contrast of 0.10 brill. Thus, in reducing the area from 4° to 1°, the contrast would probably fall from 0.19 to 0.10 brill.

Defective Night Vision.

Not everyone can see equally well at low intensities. The illuminating engineer will not be concerned to legislate for the completely night-blind persons, as these are not numerous and cannot help but realise their defect. The more difficult problem is to discover how many persons require, say, four times the amount of light to provide them with the seeing power of the normal person and, having found them, to decide whether they should, for example, still be allowed to drive a car in the black-out, whether, as pedestrians, they should be accompanied at night by someone else, whether the lighting installations should be adjusted to take account of their deficiency, or whether their deficiencies should merely be ignored.

To enable tests to be carried out on large groups of people the author recently designed a simple test for night vision, which is now being put on the market by Messrs. Pitman. The test provides a faint light source of radium luminous compound that is used to illuminate any one of a series of cards of a broken circle printed in grey on a black background. One card differs from another in being printed in a lighter or darker grey, and the object of the test is to determine the darkest card that can be seen after a given period of dark adaptation.

Preliminary results on nearly 300 persons indicate

that some 5 per cent. require more than four times the light needed by the normal person. For some activities this is likely to prove a serious handicap. The rate of adaptation may also be an important factor for some tasks, and tests show that some persons adapt more rapidly than others ([15]); more observations, however, are required before a systematic analysis is possible.

Design and Operation of Brillmeter.

The optical system of the brillmeter, shown in Fig. 3, is extremely simple. A 4-volt lamp, S, illuminates a diffusing screen D, in front of which is a circular aperture A. A stepped wedge W provides a means of varying the intensity of the light patch,

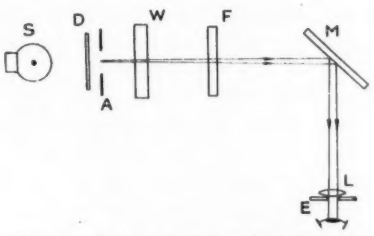

Fig. 3. Optical system of the brillmeter.

the density range of the wedge being from 0—2.0, in density steps of 0.2. If required, a neutral filter can be inserted at F to extend the density range; the light is then reflected by a mirror M into the eye lens L. A small artificial pupil E limits the cone of light entering the eye, which, when placed behind E, sees the aperture A focused at infinity, this aperture being situated in the first focal plane of L. The angle subtended by A is about 1°.

The brillmeter is designed to be used by the left eye, and the purpose of the mirror M is to throw the bulk of the system to the left of the head and so avoid obstructing the field of view of the right eye. It is important that the exit-pupil of the instrument should be fixed central relative to the left eye pupil([16]), and a mouthpiece mounting is accordingly provided ([11, 16]). The dental impression plate is attached to a horizontal geometric slide, which is, in turn, attached to the vertical arm of the instrument by means of a second geometric slide. The arrangement, and that of the brillmeter as a whole, can be seen from Fig. 4. The slides have to be adjusted to centre the pupil correctly; they can then be clamped and no further alterations are required. The instrument can be picked up and the observer bite on the plate and make his observations straight away. The dental impression, in fact, avoids much of the difficulty encountered with hand photometers, in that the patch is difficult to find and awkward to maintain in the field of view. The weight of the instrument is, of course, taken by the hand and not by the teeth.

So far, the brillmeter has only been used for low-intensity work, and its operation is then as follows: The left eye is dark-adapted with an eyeshade and

Fig. 4. The brillmeter.

bandaged for thirty minutes. The bandage is removed, and, while the brillmeter is being fixed in position in the mouth, the left eye is kept shut. The left eye can then be opened, and by using an eyeshade with a small hole in it, it is possible for the left eye to remain effectively dark-adapted, at least when working at low intensities. The observation then consists of making a brightness match between the patch seen in the left eye and whatever test object is being viewed in the right eye. When making the match it is necessary, to avoid summation effects between the two eyes, to direct the instrument so that the brillmeter patch is seen projected against a dark area of the right eye field of view. This presents little difficulty when working at low illumination levels, but may be a more awkward condition to satisfy in daylight experiments. The writer had been warned some time ago by Dr. Craik that this difficulty would

arise, but had hastily concluded, from some previous experiments, that the two images could be kept mentally separate.

It is, of course, impossible to attain an accuracy of the same order as that attained in ordinary photometry. This is implied in the use of a stepped wedge, with which a reading can only be obtained to the nearest density step, so that an error of at least ± 0.1 in density is always possible. This low accuracy has the advantage that none of the usual photometric refinements has to be employed. The instrument can be calibrated directly in brills by making a series of matches on extended surfaces of known physical brightness.

Acknowledgments.

Although this paper does not present the results of any systematic research, the author desires to acknowledge the financial help of the Medical Research Council, through which he was able to have the brillmeter constructed. He would also like to express his thanks to Mr. E. Shand for his help in the workshop at the Imperial College with the design and construction of the brillmeter.

Finally, he wishes to record his appreciation of the interest taken in these researches by Mr. A. W. Beuttell, a Past-President of the Illuminating Engineering Society, who is responsible for some of the earliest pioneering work in this field.

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Demonstration of War-time Street Lighting

Following the delivery of Dr. Wright's paper, Mr. J. S. Dow recalled the presentation, at the last meeting, of the Report on War Time Street Lighting, now also available for discussion. He pointed out that data in Dr. Wright's paper confirmed the conclusions therein in several important respects.

Mr. Dow then showed some demonstrations illustrating points dealt with in the report. A series of discs of varying diameter and lifesize cardboard figures of people wearing clothes of different colour were seen against a neutral background of reflecting power similar to that of the average roadway. After inspection at relatively high illuminations the value of the illumination was reduced by stages to 0.2, 0.02, 0.002, and 0.0002 foot-candles, and the effects observed. The effect of size of object on apparent brightness at this low illumination was illustrated by the appearance of the circles—those of smallest diameter being apparently less bright and difficult to see by direct vision, though at normal illumination all appeared equally bright and distinct.

Useful lessons could also be drawn from the appearance of the figures. For example, a white colour or glove seemed too small an area to provide certain identification. It was also evident that figures in light clothing were very much less distinguished, under war time street lighting conditions than those in dark clothing—though the contrast with the background was of the same order and at high illuminations both sets of figures appeared equally distinct. Mr. Dow invited explanations of this somewhat unexpected phenomenon.

In conclusion the influence of signs of varying brightness on the appearance of the figures when placed in their immediate vicinity was illustrated. At the 0.0002 level a sign having a brightness of 0.02 e.f.c. produced no appreciable glare, whereas one of about 1.5 e.f.c. (about the value specified for white traffic "crosses") did interfere appreciably with the distinctness of the figures, and one of about 30 ft.c. almost obliterated their outlines. At somewhat higher illuminations, however, visibility improved, and effects of glare became less, thus confirming the belief expressed in the report that somewhat higher local illuminations might be of substantial benefit.

DISCUSSION.

Dr. K. J. W. CRAIK said he was asked by the Medical Research Council, under the auspices of the Illuminating Engineering Society, about a year ago, to carry out some work similar to that done by Dr. Wright on the measurement of subjective brightness. First, he made an apparatus rather similar to that described by Dr. Wright for measuring subjective brightness, and he encountered the difficulty, which he believed Dr. Wright met, in making a match between the artificial field in one eye and the natural

field, in that one was more or less bound to project the comparison field on to the true field and get them summated. He got over that, however, by using a filter with a hole in the middle in front of one eye to look at the true field. In that way it was possible to make an accurate match, but the colour difficulty still remained. In view of that, his own preference was for another instrument (this was exhibited by Dr. Craik) which was extremely simple and did not require a battery, and it also gave a measure of subjective brightness. The purpose in seeing, continued Dr. Craik—except in a few cases like theatre lighting—was usually to do some task. It was not just a question of whether the lighting looked nice. His object in devising the second instrument was to test such things as acuity, discrimination of contrast, speed of reading, and performance of small work. The result of tests showed that these functions varied from a maximum down to about $\frac{1}{100}$th in the various classes, so that roughly one could specify a ratio of 100-1 in which various tasks could be performed, using a surface evenly illuminated by 100 ft.c., or in daylight, to get maximum efficiency. A smaller illumination gave a reduced efficiency. This instrument measured both efficiency and the effect of glare source. In demonstrating and describing the instrument, Dr. Craik explained that it must be held 12 in. or thereabouts from the eye and turned until the aperture at the centre was completely dark. He added that the results obtained with the instrument seemed to agree with actual facts and also explained how by varying the position of the angle-poise lamp the efficiency could be varied and how trouble from shadows could be avoided.

Dr. J. W. T. Walsh said he had one small point to mention and also a question to ask Dr. Wright, a question which he had already asked several people but without receiving any satisfactory answer. He was very pleased that Dr. Wright now repeated what he had said before, viz., that it was impossible to measure subjective brightness. In view of that, however, he was a little worried by the formula and the unit proposed. He did not mind the name "brill" —all new names came as a shock at first—but there seemed to be a little danger in putting forward a definite scale and giving a particular magnitude to a unit of something which admittedly could not be measured. He imagined that Dr. Wright had done that in an effort to fill the need to the best of his ability. In the hands of those who were used to these things it would probably be quite safe, but a certain amount of misconception might easily arise and this could lead to rather remarkable results if the limitations of the system were ignored. For instance, it was clear that the brill would not add. That was obvious from Table 1 because although physical brightnesses of 0.1 and 1 could, of course, be summed, the corresponding brills added up to a thing which corresponded to a physical brightness of 100. Thus the ordinary method of manipulating units had to be completely forgotten. It seemed to him that perhaps there was a case for trying out the scheme proposed by Dr. Wright and seeing how we got on with it.

With regard to his question, Dr. Walsh said he did not know whether it should be addressed to Dr. Wright or to Mr. Dow. He had noticed repeatedly—and his experience had been checked by others—that his detection of quite large objects under blackout conditions when wearing spectacles—which he had recently had to take to continuously—was very much inferior to what it was if he took his spectacles off. He did not know why that should be so. As an example, he had noticed that when looking at the four white discs which Mr. Dow had demonstrated, with the very low illumination all the discs appeared very fuzzy when he wore his spectacles, and the small disc was practically not seen at all, but when he took his spectacles off he could see all four discs very much more clearly. The same applied also to the figures which Mr. Dow had shown, although the effect was more noticeable in the case of the discs.

Mr. Percy Good said the subject dealt with by the two papers was one which some committees of the Society had been very actively interested in for a long time, and he only regretted that these sort of studies had not been made a long time ago.

Referring to Dr. Wright's paper he said he had some anxiety concerning the new unit "brill." He would have thought we could have retained the expression "apparent brightness," without having a new unit. Nevertheless, the curves shown would be very useful for those responsible for war-time conditions.

With regard to the Report which Mr. Dow had introduced, this made it very clear how necessary it was, if blackout conditions were to continue for any considerable time, to review many of the conditions

which had hitherto been established in regard to seeing under war-time conditions. It was quite obvious that much could be learned from both documents which would result in substantial improvements in regard to aids to movement under blackout conditions. One could not but be impressed by the very large increase in the number of casualties on the roads under blackout conditions, and he felt quite certain that effective use of the knowledge which was summarised in these two papers would lead to improvements which would diminish these casualties.

These subjects were deserving of close study and the Society was to be congratulated on having two papers which should take us a long way towards making greater use of this knowledge in assisting the general war effort.

Dr. J. H. NELSON, referring to the suggestion that the apparent brightness scale should be used primarily for low intensities, asked to what extent this applied to coloured lights under low intensities, and if the " white " used had any appreciable effect.

Speaking of what Dr. Walsh had said with regard to the use of spectacles, he said he found it necessary to use them as much in the dark as in the daytime. Incidentally, he mentioned that when going out into the blackout in the morning he had found it took very much less time to become dark adapted than when in the blackout at night, taking the same levels of brightness.

The PRESIDENT remarked that going out in the morning was after having had a night's rest.

Dr. Nelson agreed, and said he did not realise there should be the really phenomenal difference there was.

Mr. L. T. MINCHIN said the " brill " did not seem to be sufficiently different from the effective foot-candle. The only difference, apart from the mathematical calculation, consisted in the word of the dark adapted observer, and it seemed it would be more useful to have a unit of subjective brightness which included in it somewhere the level of dark adaptation of the eye. If we could have a unit which even only approximately compared the brightness of objects seen on a moonless night with the brightness of objects seen on a starry night, that would give a formula which provided an idea of the adaptation. Had Dr. Wright considered a formula of that kind? In his view, there would be more justification for it.

With regard to the demonstration Mr. Dow had arranged, Mr. Minchin suggested that the earlier disappearance of the man in black coat, whose contrast with the background was similar at higher illuminations to that of his lighter attired neighbours, could be quite simply explained. The amount of light reaching the eye from the system black coat + medium background was substantially less than that coming from the system light coat + medium background, even though the contrast might be the same.

Mr. J. M. WALDRAM said that it was necessary to be quite sure that Dr. Wright's proposed unit, the " brill," was really justified before it was adopted. The transformation which he had suggested was correct only for one of a good many practical cases. There were many problems which would not be correctly represented by the " brill," and it was necessary to make corrections for adaptation and also for area effects, colour effects, etc. There might be another method of doing the same thing, as Dr. Wright had suggested, but in a more universal way. A series of curves for various adaptation levels could be standardised instead of one, similar to those given by Dr. Hopkinson. They might be just as arbitrary as Dr. Wright's single curve but might not necessarily have any elaborate basis so long as they gave results which were approximately correct. Such a series of curves would enable the problem, of numerically representing visual sensations, to be separated into two parts, which he thought was possible. In the first place there was photometry, which was a distinct problem of measurement for which it was necessary to use a series of numerators obeying the rules of arithmetic. In the second place there was the question of turning the final photometric results into numbers which approximated to sensation, which meant some such transformation as that indicated by Dr. Wright, one which would take into account the observer's adaptation level, and possibly area, colour, etc. If something on those lines could be done it would avoid the temptation to use the proposed unit for purposes for which it was not adapted.

Mr. C. E. GREENSLADE congratulated the author on his attempt to provide a new unit, and said the only thing he had to quarrel with was the name " brill." It was a logarithmic unit multiplied by ten and might get mixed up with the " decibel," which was used in wireless telephony. However, a unit by which an attempt was made to measure something, whether accurate or not, was a distinct step forward. With regard to vision in weak light, there had been no reference to what would be done in similar circumstances. If

one's sight was not very satisfactory one wore glasses, and under these low illuminations he suggested the use of strongly negative glasses under blackout conditions. Although it made objects seem very much smaller it was possible to walk along quite comfortably under conditions which, without these glasses, would be almost impossible. He had often a long walk home, usually in the blackout, and had found these glasses a great help.

Dr. K. NORDEN drew attention to an effect of low levels of illumination, which had not been mentioned so far. This referred to what he termed the misinterpretation of shadows. They were all familiar with the fact that shadows which were cast by objects could easily be mistaken as to their nature. For instance, the shadow of a lamp-post falling across a highway might very easily be mistaken for a transverse ditch or a mound, and this could lead to wrong movements on the part of a driver or pedestrian. Such misinterpretations are more likely to occur in twilight vision which does not enable the formation, structure, or colour of the shadowed road surface to be recognised. Therefore, the avoidance of shadows which were liable to misinterpretation was still more important under low levels of illumination.

Mr. A. W. BEUTTELL (*Communicated*):—The paper is to be welcomed as another definite step towards the understanding of subjective brightness and the importance of its recognition in lighting practice.

Dr. Wright has marked the step by courageously proposing a new unit, the "brill," and hence a scale of practical values. The effect is to place in the hands of engineers the possibility of measuring illumination in terms of its value to the human eye instead of the foot-candle. It would be interesting to know how many people who deal in foot-candles are fully aware of the fact that "15 ft.c." is only a statement of the density of physical light falling on an object, and that it gives no information at all about the value of it to the eye. The latter depends on the attendant conditions, such as adaptation and glare, and it can only be known when these are taken into account, and it is measured in terms of its subjective value. Hence the "brill." Remembering the fact that the eye alone has any practical use for illumination as such, I hope it will not be long before we recognise and insist upon it that the useful *effect* of light shall be measured in the same terms that the eye measures it and not in terms that give an entirely different answer because they ignore the eye altogether. The foot-candle should only be used in relation to the *amount* of light provided.

Dr. Wright and Dr. Craik have both offered instruments which gave at least an approximation to brightness as the eye sees it. They have proved that a given equivalent foot-candle brightness may be either very "bright" or very "dark," and they offer to show us which and how much. Let us encourage this line of attack on a very neglected problem.

Dr. W. D. WRIGHT, replying to the discussion, said he had had conversations and long correspondence with Dr. Craik, and was very interested in his experiments. There was not the slightest doubt that Dr. Craik's instrument would be very valuable in measuring the efficiency of lighting systems, but in so far as acuity, performance of small work, and so on, were not of major importance in low intensity problems, he was inclined to think that it was not the instrument required for very low intensity investigations. As he had indicated in the paper, the summation between the two eyes caused practically no difficulty when using the brillmeter at low intensities, because there was almost always a dark area in the field of the right eye against which the instrument patch seen in the left eye could be projected.

With regard to the various comments that had been made about the subjective brightness scale, he said that he had put forward the scale in order that some progress should be made in the matter, and although one stage in such progress would be that stones should be thrown, he did not think his critics had thrown the right stones. Dr. Walsh was not on very good ground when remarking that the unit did not add up, because the National Physical Laboratory used the phon, and that seemed to work all right (laughter). He had tried to make it clear in the paper that the brill scale did not, and could not, be used to measure sensations, but if it were the right scale then it might be used to measure sensation intervals or contrast. He did not think there should be any difficulty in working with the scale, and if trained illuminating engineers were the only people who understood such matters, they would be all the more valuable to the community. As to the name "Brill," he had merely put it forward tentatively and any change would not worry him, but it seemed to him an appropriate name. He did not agree with Mr. Good that "apparent brightness" was equally satisfactory. When it appeared many times in a paper its use became rather irritating, and he felt

that one of the advantages of having a definite scale and unit was that it helped to simplify the terminology and make the discussion more concise and precise.

It appeared that neither Mr. Minchin nor Mr. Waldram had quite understood the scope of the brill scale. By defining the brills on the basis of observations made by a lark-adapted observer, he had provided a perfectly definite scale that could be used for all values of subjective brightness. There was in theory no need for any other scale, although, as he had indicated in the paper, it might in practice prove convenient to employ a sub-standard scale at a higher adaptation level. The measurement of apparent brightness for levels of adaptation other than dark adaptation might, as Mr. Waldram suggests, be carried out by having a series of brill curves for various adaptation levels and then measuring the physical brightness of the test object in question, and determining the adaptation level of the eye when viewing that particular scene. But it was not easy to see how the latter determination could be made very readily, and since the apparent brightness of the object depended on its size and on the contrast from neighbouring objects in the field of view, some allowance would have to be made for these factors. He thought it would be quite impossible ever to develop a formula by which such allowances could be made correctly; the only thing to do was to let the eye do the work instead. This was what happened when using the brillmeter; the object to be measured was seen in its natural surroundings by the eye adapted to the level of the scene as a whole, and the apparent brightness was measured by comparing it with a patch seen by the dark-adapted left eye. It was thus evident that the brill scale used in conjunction with the brillmeter could be employed for all the conditions referred to by Mr. Minchin and Mr. Waldram, and it was difficult to see how the same result could be achieved by any method other than that of binocular matching. The difference between the brill and the effective foot-candle was, of course, that the brill took account of the change in subjective brightness as the intensity was reduced, while the the effective foot-candle was concerned with the change in subjective brightness with wavelength. The effective foot-candle could not, for instance, be used for the specification of contrast. It might be possible to combine the effective foot-candle with the brill and so allow for the effect of colour, and so solve the problem raised by Dr. Nelson and others, but no attempt had yet been made to do this. He was very interested in the change found by Dr. Nelson in the time required to become dark-adapted at night compared with the morning, and was also surprised at the magnitude of the effect.

Replying to Dr. Walsh's question on the use of spectacles, he expressed the view that he would not have thought the use of spectacles at low intensities would have made any difference, and certainly had not noticed such an effect himself. It suggested that with some people at least the normal state of accommodation was different at low intensities, but since we were not usually concerned with fine visual acuity at such intensities, it was surprising to find an effect as marked as Dr. Walsh indicated.

Election of Mr. Alexander Pelham Trotter as Honorary Member

The Articles of the Society provide for the election by the Council of Honorary Members who "may be chosen from among those who are of acknowledged eminence in some branch of science relating to illuminating engineering, or who, by reason of position, eminence, or experience, have rendered, or may be enabled to render, assistance in promoting the objects of the Society." It is further prescribed in the By-laws that not more than one honorary member may be elected in any one year, and that the total number at any time may not exceed six.

Of the eminent experts on photometry and illumination thus honoured in past years none is now surviving, the last being Professor André Blondel, who passed away in 1938.

The Council has now elected to this position Mr. Alexander Pelham Trotter. Mr. Trotter's long and honourable association with illuminating engineering is unique. Born in 1857, he was educated at Harrow and at Cambridge under Clerk Maxwell. It is approximately sixty years since he commenced his pioneering work on illumination photometry and his early researches on prismatic glassware and on other kindred problems. A member of the Society since its foundation, he has taken an active part in many of its Committees. He became President during the Great War (1917) and continued in office until after its termination (1921).

During this period he presided over a Committee of the Society concerned with special experimental work for the Ministry of Munitions, and served in the City of London Volunteer Regiment of the National Guard. He also assumed the Chairmanship of the Joint Committee on Illuminating Engineering, appointed in 1917, under the Department of Scientific and Industrial Research.

On many occasions subsequently he has given evidence of his keen interest in the aims and objects of the Society, and only last year he contributed to the "Photometric Reminiscences," which formed the subject of one of its informal gatherings.

ELECTION OF OFFICERS AND COUNCIL
SESSION 1941-1942. OFFICIAL NOTICE

IN accordance with the procedure specified in the Articles of the Society, a list of existing Officers and Members of Council, of vacancies occurring and of duly qualified persons nominated by the Council for vacancies about to occur in the offices of President, Vice-Presidents, Hon. Treasurer, Hon. Secretary, and Ordinary Members of Council, is presented below for the information of the Members of the Society.

In the event of any Members desiring to put forward other names, the Council will be pleased to receive such nominations, which should be made in accordance with the following rule (Article 48) :—

> "After the issue of the Council's list, and not later than the *15th day of April* next following, any ten Members (but no more than ten) may nominate any other duly qualified person to fill any such vacancy by delivering such nominations in writing to the Hon. Secretary, together with the written consent of such person to accept office if elected, but each such nominator shall be debarred from nominating any other person for the same office at such election."

Present Officers and Members of Council

President :—*Professor Dr. J. T. McGregor-Morris*, *M.I.E.E., F.I.E.S.*

Past Presidents :—

Mr. A. P. TROTTER, M.INST.C.E., F.I.E.S.
Sir JOHN HERBERT PARSONS, C.B.E., F.R.S., F.I.E.S.
Sir DUNCAN WILSON, C.V.O., C.B.E., F.I.E.S.
Dr. C. C. PATERSON, O.B.E., M.INST.C.E., M.I.E.E., F.I.E.S.
Dr. J. W. T. WALSH, M.A., M.I.E.E., F.I.E.S.
Lt.-Col. K. EDGCUMBE, T.D., M.INST.C.E., M.I.E.E., F.I.E.S.
Lt.-Com. HAYDN T. HARRISON,
Mr. C. W. SULLY. [M.I.E.E., R.N.V.R., F.I.E.S.
Mr. H. HEPWORTH THOMPSON.
Mr. A. W. BEUTTELL, M.I.E.E., F.I.E.S.
Mr. A. CUNNINGTON, B.SC., M.I.E.E., F.I.E.S.
Dr. S. ENGLISH, F.I.C., F.INST.P., F.I.E.S.
Mr. PERCY GOOD, M.I.E.E., F.I.C.G., F.I.E.S.
Mr. F. C. SMITH, M.INST.GAS E., F.I.E.S.

Vice-Presidents :—

Mr. R. O. ACKERLEY, F.I.E.S. (1939)
Dr. H. BUCKLEY, F.INST.P., F.I.E.S. (1940)
Mr. E. J. STEWART, M.A., B.SC., F.I.E.S. (1940)

Members of Council :—

Mr. T. C. Angus (1938)
Mr. T. Catten (1939)
Mr. DEAN CHANDLER (1939)
Mr. W. N. C. Clinch (1938)
Mr. R. W. DANIEL (1940)
Mr. L. J. Davies (1938)
Mr. G. DIXON (1940)
Mr. W. J. EDWARDS (1939)
Mr. N. V. EVERTON (1940)
Mr. G. W. GOLDS (1940)
Mr. C. E. GREENSLADE (1939)
Mr. A. V. Horsfall (1938)
Mr. J. W. HOWELL (1939) *
Mr. H. LINGARD (1939)
Mr. HOWARD LONG (1940)
Mr. R. MAXTED (1940)
Mr. C. W. M. PHILLIPS (1940)
Mr. T. E. RITCHIE (1939)
Mr. K. F. SAWYER (1939)
Major P. A. Smith (1938)
Mr. E. STROUD (1940)
Mr. J. M. WALDRAM (1940)

Hon. Secretary :—*Mr. J. Stewart Dow* (1928)
Hon. Treasurer :—*Mr. E. W. Murray* (1939)

Nominated by the Council to fill Vacancies

President :—Mr. W. J. JONES, M.SC. M.I.E.E., F.I.E.S.

Vice-Presidents :—

Members of Council :—

Mr. T. CATTEN
Dr. W. M. HAMPTON
Mr. J. S. PRESTON
Mr. E. B. SAWYER
Mr. CRAWFORD SUGG
Mr. H. C. WESTON
Dr. W. D. WRIGHT

Hon. Secretary :—Mr. J. STEWART DOW
Hon. Treasurer :—Mr. E. W. MURRAY

The names in italics are those of retiring Officers or Members. The date in parentheses after each name indicates the date of election to Office or Membership of the Council. * Chairman of the North Midland (Recognised) Local Centre; Chairmen of other Local Centres are now invited to attend Council Meetings during their tenure of office.

NOTES ON RECENT MEETINGS AND EVENTS

Sessional Meeting in London.

At a sessional meeting held in London on February 11 a paper entitled "The Recognition of Coloured Light Signals" was read by Mr. J. G. Holmes. The Paper, which contained a record of a considerable amount of research work on this subject, led to an interesting discussion, in which the following took part: Dr. W. M. Hampton, Mr. N. E. G. Hill, Dr. W. D. Wright, Mr. J. S. Dow, Mr. J. W. Perry, Mr. A. Dinsdale, and Mr. R. Maxted.

After the President had wound up the discussion and Mr. Holmes had briefly replied, a vote of thanks to the author and to the E.L.M.A. Lighting Service Bureau for their hospitality terminated the proceedings.

Meetings in Local Centres.

Local Centres have been in the main successful in carrying out the earlier parts of their programmes (see "Transactions," Sept., 1940, p. 122), though war conditions have more recently led to the postponement or cancellation of some events.

The North Midland Centre arranged an informal luncheon on November 11, at which over 100 members and guests were present. The toast of "The Illuminating Engineering Society" was proposed by Mr. C. S. Shapley (engineer and manager of the Leeds Gas Department), supported by Mr. A. H. Owen (hon. sec., North-Western Local Centre) and Mr. H. Dixon (president of the Institution of Gas Engineers). Mr. J. W. Howell, chairman of the North Midland Centre, responded.

Mr. R. Maxted has been responsible for a paper on "Industrial Lighting in War Time," which has been read before various Local Centres and sub-centres, including the Midland (October 11), North Midland (October 14), North Western (October 12), Scottish (October 16), Nottingham (January 31) Centres. This paper will appear in the "Transactions" in due course.

The address delivered by the President in London on October 8 was repeated with great success before the Local Centre in Glasgow on December 18, 1940, and the paper on "The Photometric Properties of Luminescent Materials," previously presented by Dr. W. E. Harper, Miss Margaret B. Robinson, and Mr. J. N. Bowtell, in London, on April 9, was also repeated at meetings of the North-Western Local Centre on November 25, and of the Nottingham Local Sub-Centre on November 29. At a meeting of the North Western Local Centre on December 12 a series of short contributions by local members was presented, and led to a very interesting evening.

In the Midland Area, where the programme for the session was inevitably interrupted, new dates for meetings in April, May, June, and July have now been arranged.

I.E.S. FELLOWSHIP.

Applications for Fellowship on behalf of the following have been accepted by the Council:—

Barton, P. S. ..... 43, Quakers Lane, Potters Bar, MIDDX.
Cator, F. L. ..... 25, Vicarage Road, Handsworth, BIRMINGHAM.
Hughes, C. J. A. ..... 16, Ashley Court, Epsom, SURREY.
Iliffe, A. E. ..... The Benjamin Electric, Ltd., Tariff Road, Tottenham, LONDON, N.17.
Monash, Dr. B. ..... 7, Ellesmere Road, Windsor, S.1, Melbourne, Victoria, AUSTRALIA.
Murray, E. W. ..... Home Office Industrial Museum, Horseferry Road, LONDON, S.W.1.
Pogson, W. F. ..... 4, Albion Street, LEEDS, 1.

APPLICATIONS FOR MEMBERSHIP.

Elections Pending.

The names of the following applicants for membership were presented for the first time at the meeting held on February 11, 1941:—

CORPORATE MEMBERS:—

Brain, A. S. ..... "Hillside," Little Sutton Road, Four Oaks, WARWICKSHIRE.
Ingham, T. H. ..... "Brooklyn," Bradford Road, Tingley, Nr. WAKEFIELD.
Knowles, G. E. W. ... Eland, Settle, YORKSHIRE.
Oswin, F. ..... 58, Tillottson Road, Lower Edmonton, LONDON, N.9.
Potts, L. J. ..... 39, Bennett's Hill, BIRMINGHAM 2.
Rush, F. N. ..... Metropolitan Vickers Electrical Company, 79, Downs Park Road, BRISTOL, 6.
Stanley, J. F. ..... The British Standards Institution, 28, Victoria Street, LONDON, S.W.1.
Wright, N. E. ..... 148, Montague Avenue, Oakwood, LEEDS, 8.

COUNTRY MEMBER:—

Saunders, J. B. ..... 27, Edward Road, West Bridgeford, NOTTINGHAM.

Elections Completed.

The list of applicants for membership whose names had been presented at the previous meeting on January 14 (Trans. Vol. VI., No. 1, p. 15) was again presented, and these gentlemen were formally declared members of the Society:—

TRANSFERS FROM COUNTRY MEMBERSHIP TO CORPORATE MEMBERSHIP:—

Anketell, R. C. ..... Turnbull and Jones, G.P.O., Box 1669, Wellington, NEW ZEALAND.
Chapman, F. E. ..... 133, Rough Road, Erdington, BIRMINGHAM, 23.
Forth, J. W. ..... 137, Corporation Road, DUDLEY.
Gibbs, L. E. ..... White Walls, Balsall Common, WARWICKSHIRE.

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BRIGHTNESS AND CONTRAST IN ILLUMINATING ENGINEERING

By R. G. HOPKINSON, Ph.D., A.M.I.E.E., F.R.P.S. *(Member)*, W. R. STEVENS, B.Sc. *(Fellow)* and J. M. WALDRAM, B.Sc., F.Inst.P. *(Fellow)*

(Research Laboratories of The General Electric Company, Limited, England).

(Delivered on Tuesday, December 10th, 1940).

1. Contrast and Recognition.

A discussion of "contrast" necessarily involves the whole process of seeing, for whatever may be its precise meaning "contrast" is recognised as one of the factors which help to make things visible, and its interest lies in its ability to do so.

We tend to think of the eye as merely an apparatus for the perception of light; and much of the discussion of the eye in technical literature has led the technical reader to this conception, partly as a result of the necessary restriction of experiments to simple cases. But the process of seeing is infinitely more subtle than the perception of light. It was once remarked that "the eye is a very bad photometer"; but it would have been wiser to have said that "the photometer is a poor gauge of seeing," for seeing is the gathering of intelligible information from the light reaching the eyes, and it stands in much the same relationship to perceiving light as does the appreciation of music to the perception of sound. We have studied the ability of the eyes to perceive fine detail, low brightnesses, small colour differences, and so forth; but the step from these measurements to the use of our eyes in everyday seeing is very much like the step from measurements of the perception of loudness and timbre to the understanding of music or poetry.

Seeing does not even depend upon the perception of light alone. For example, in a thick fog by day there is plenty of *light* to be perceived, but we remark, "I could not *see* a *thing*!" It is "things" not light which we are interested to see; and we cannot see in a fog not because there is no light but because there are no darknesses to make a recognisable pattern. But a kaleidoscopic pattern of light and dark and colour, which presents plenty of material for the eye to perceive, may give no *information* at all (Fig. 1); and yet a few lines (Fig. 2)* may

Fig. 1. Contrasts conveying no information.

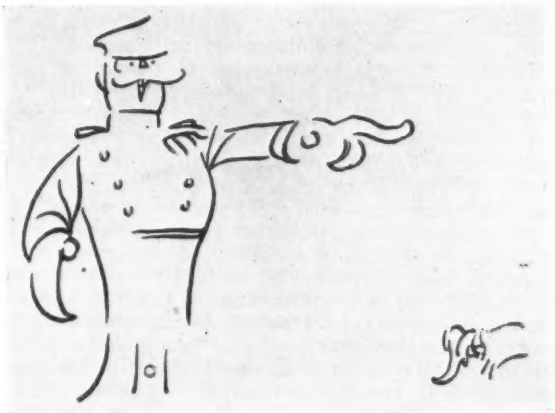

Fig 2. Information conveyed by geometry alone.*

convey a very definite impression, with a good idea of expression, age, sex, character, etc., even though the lines have made no attempt correctly to represent contrasts, colour, or many of the important details. It seems that we see not by light alone, nor by darkness alone, nor by contrast, nor colour alone, but by recognising the familiar geometry of the brightness and colour contrasts presented to us. Even a crude indication of this geometry may be sufficient to give a great deal of information either directly or by inference. Recognition thus depends upon

(1) the amount of contrast and colours;
(2) the geometry of their boundaries and distribution;
(3) familiarity with the scene.

2. Meaning of "Contrast."

The term "contrast" is used in many senses other than the visual, and its use gives the key to its meaning. We speak of the contrast in music, between, say, a quiet and delicate passage for wood-wind and a succeeding fortissimo passage with the full orchestra: of the contrast of character between, say, two members of the same family: of the comical contrast of a short, fat man beside a tall, thin

*We are indebted to Messrs. Hutchinson and Co. (Publishers) Ltd. for permission to reproduce from "Fun Fare," this apt sketch by Fougasse.

man, and so on. In all these cases, as well as in contrasts in brightness and in colour, contrast means "*the sensation of difference between juxtaposed things.*" The contrasting things may be juxtaposed in time or in space, as the above examples show; visual contrasts generally occur between objects juxtaposed in the field of view. The important point in the definition is that contrast is a sensation of difference. The sensation must arise from a physical difference in photometric brightness or in spectral distribution, but it is not identified with the physical difference; the same physical differences may produce in various circumstances "sensations of difference" (i.e., contrasts) which are not the same. On the other hand, some kinds of physical difference (for example, of spectral distribution) may produce no contrast at all: this is what occurs when a trichromatic colorimeter is balanced.

Since contrast is a sensation, it is resident in the observer and it cannot be measured directly. All that can be directly measured are the brightnesses and spectral distributions which bring it about; the contrast itself must be gauged from these measurements by experience of similar situations or otherwise (see Section 4D). There is, however, one quantity sometimes known as contrast in which the word has a specialised meaning, which must not be confused with the sense in which it has been used above. The photographer uses "contrast" to express a characteristic of sensitive materials and processes, and in this sense it is a definable and measureable physical quantity. Broadly speaking, it represents the relationship between a brightness ratio in the original scene to the corresponding brightness ratio in the reproduction of that scene. It is a measure of the degree to which the material or process over-or under-emphasises brightness differences in the original. It is generally expressed as the slope of the curve of density plotted as a function of the logarithm of the exposure, and is often known as "Gamma."

3. Range of Brightness Response.

The enormous range of brightnesses to which the eye will respond is often pointed out: in problems of vision in the black-out it is necessary to consider brightnesses below one millionth of an equivalent foot-candle; in a sunlit snow scene the brightness may be over 10,000 equivalent foot candles. The absolute overall range is about 10^{12}:1. But the eye cannot cover the whole of this enormous range *at once*, and it is much more important in practical seeing to consider what may be called the instantaneous range of the eye. There is an analogy with an electrical test set, which may be a milliammeter provided with a set of shunts. The unshunted instrument may be able to measure satisfactorily currents as low as 0.1 milliampere; with the largest shunt in the range it may be able to measure 100 amperes, so that its total useful range is 1 million to 1. But with any one shunt its useful range is only about 20:1: with the 10-amp shunt connected, variations of 10 milliamps will not be indicated, while currents of 100 amps will damage the instrument. The eye functions very similarly; it is like a milliammeter or oscilloscope which automatically selects a shunt which will bring conveniently on the scale the whole of a range of varying currents applied to it. It cannot, however, deal with too great a variation at once, and if an excessive variation is applied to it, then the maxima will be off the scale and may cause damage, or the minima will not be distinguishable from zero. In much the same way a radio receiver with automatic volume control adjusts its gain automatically to suit the level of the incoming signals; but exceedingly strong or very weak signals may lie outside the capabilities of the a.v.c. circuit and the output will be distorted.

These two analogies illustrate two phenomena of the eye which are important in seeing. The first is that the instantaneous range of the eye is limited, and it cannot simultaneously respond to very high and to very low brightnesses, or deal with one brightness of small extent which is very different from the general level to which the eye is adapted. The second is that as the general level of brightness of the scene is reduced, there comes a point when the darker parts of the scene fail to register as sensations; the eye has adapted as far as it can, but they are still too dark to be seen. Moreover, as the general brightness of the scene is reduced, relative brightness differences which were clearly distinguishable at the higher brightness levels become much less visible at lower brightness levels; the sensitivity of the eye to small differences of brightness is reduced so that a given relative change of brightness produces a less sensation.

For example, when the eye is adapted to a brightness of 1,000 e.f.c. brightnesses below 5 e.f.c. appear black, although when dark-adapted a brightness of 5 e.f.c. appears uncomfortably bright. When one is out of doors on a bright sunny day, the eye is adapted to a brightness of about 1,000 e.f.c., and little can be seen through an open door of the objects in a room indoors. The prevailing brightness inside the room may be of the order of 10 e.f.c., so that all but the brightest objects will be darker than the lower limit of brightness of the eye adapted to a level of 1,000 e.f.c. If one enters the room, the eye adapts to the average level of 10 e.f.c., and the objects in the room become distinguishable, for their brightnesses are within the useful range to which the eye will now respond. Most of the objects outside the window can also be distinguished, because they are still within the range of the eye adapted to 10 e.f.c., but it may be found that white clouds, seen through a small window, appear as glaring white masses devoid of detail, because the brightnesses here are beyond the upper limit for an average brightness of 10 e.f.c.

Similarly, when one leaves a brightly lighted room for the conditions of the black-out, hardly any detail can be resolved until the eye has had time to adapt to the very much lower brightness. In this case, however, the eye has to work under conditions near to its absolute lower limit; it can see very little of brightnesses less than the adapting brightness. Many of the objects in the field of view are below this

lower limit, and hence no matter how long the eye is given to adapt, these objects will remain indistinguishable.

The curves of Fig. 3 illustrate some of these phenomena. They represent the greatest and the least brightnesses to which the eye will simultaneously respond correlated with different adapting brightnesses. The adapting brightness is also represented by the straight line drawn at 45°. The intercept between the two curves shows the instantaneous range of the eye, and the relative positions

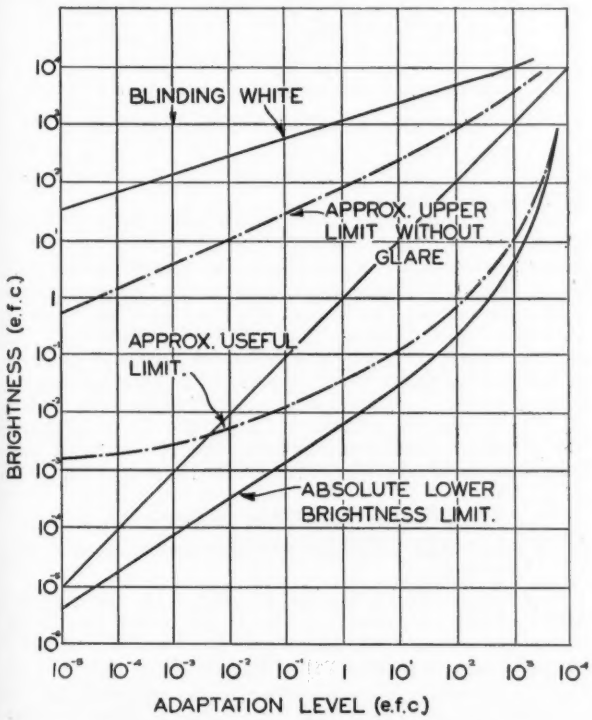

Fig. 3. Instantaneous visual range related to adaptation level.

of the ordinates on the two curves and the ordinate on the straight line shows the manner in which the range of the eye lies about the adaptation level. It will be seen that at the higher levels the range is more or less symmetrically disposed about the adaptation level; i.e., the eye can conveniently distinguish brightnesses which are both brighter and darker than the general adaptation level. But when the adaptation level is reduced the range is no longer symmetrically disposed about the adaptation level; the eye can distinguish brightnesses greater than that to which it is adapted, but not much of brightnesses less than this.

4. Effects of Range in Photographic Reproduction.

The adaptation characteristics of the eye determine the laws of photographic reproduction. In order to represent a scene faithfully, it is necessary for the brightnesses of the reproduction to give the same sensations of brightness under the given viewing conditions as did the original brightnesses which they represent. The exact mechanism, as far as it is known at present, has been described in other communications, and need only be recapitulated here.

Whilst the total range of the eye is of the order of 10^{12} to 1, the range of a good photographic paper is of the order of only 50-1, and of a good transparency of the order of 10^3 to 1. It is, therefore, quite impossible to represent on photographic paper the total absolute range of the eye.

This is, however, unnecessary. At the most the photographic paper need cover only the "instantaneous" range of the eye. Clearly, if an observer cannot distinguish detail inside a room when he is out-of-doors, there is no need for a photograph to do so.

The "instantaneous" range of the eye is of the order of 1,000 to 1, which is still greater than that of a photographic paper; but the range of brightness of the important parts of most *scenes* is seldom greater than about 30-1, so that these limitations of the photographic paper are not always such a drawback as would appear.

Provided that the range of brightness of the scene can be represented on the photographic paper or transparency, the proper densities of the photograph are then determined by the adaptation levels of the eye, both when viewing the scene and when viewing the print. The practical effect of these laws of photographic reproduction are well known. A given print viewed under changing viewing conditions may give a changing impression; for example, a photograph of a sunlit scene when viewed in bright artificial light will, if the print densities are correctly chosen, give a faithful impression of the original brilliance of the scene. If the brightness of the viewing conditions is much reduced there comes a point where the sunlight has an unreal, watery appearance, and as the brightness is further reduced the scene appears very like a scene by moonlight. Most photographers are well aware of this phenomenon and have, for example, to make a mental allowance for the difference in appearance of a print in the darkroom and its appearance in the light. Fortunately, the range of illuminations over which the print gives a faithful impression is large—roughly, from 5 to 500 ft.c. in ordinary surroundings. When the illumination falls below 5 ft.c. the correctness of a given representation will depend closely upon the illumination.

5. Subjective or Apparent Brightness.

The problems of photographic reproduction demonstrate in the most arresting manner that the brightness of an object as measured by a photometer often bears little relation to the impression of this brightness on the observer. A brightness measured with a photometer must therefore be interpreted in terms of the general adapting conditions under which the brightness will be seen. This is usually done automatically as a result of experience, but confusion

arises in unfamiliar problems or when an attempt is made to interpret brightness values in strict relationship to their photometric value.

Some system of interpretation of brightness values is therefore essential. The general consensus of authoritative opinion is, however, that sensations are not scalar or measurable, and consequently no strict relationship between physical brightness stimulus and sensation of brightness can be obtained. Some general relationship does, however, exist, and attempts to measure it have met with some success. For example, over a limited range equal increments of sensation appear to be produced by equal ratios of brightness stimulus. This is the well-known Weber-Fechner Law. This law by no means expresses the complete relationship between brightness stimulus and sensation, however, and, as a result, attempts have been made to explore this complete relationship. Of these attempts those of Abribat and of Pitt yield data which are in general agreement, although the methods employed were different.* Abribat obtained a series of curves relating brightness discrimination sensitivity with the brightness of the test field, for different values of adaptation level (see Fig. 4). From these curves he derived, by integration, the family of curves shown in Fig. 5, in which the brightness of the test field is correlated with the "sensation" of brightness produced. The validity of this integration, which was first performed by Fechner, has been questioned, but Abribat's ordinate scale of "sensation" can be reasonably replaced by an arbitrary scale of "apparent brightness." Pitt used a method of binocular matching in order to obtain his data; in this case a direct relationship between the apparent brightness and the physical brightness was obtained, without the need for any intermediate steps. Hopkinson has obtained a set of data (unpublished) using a three-part field, in which two parts formed the two comparison brightnesses, and the third part the adapting field; this method involved the assessment of large steps of brightness difference instead of just perceptible steps. The data obtained

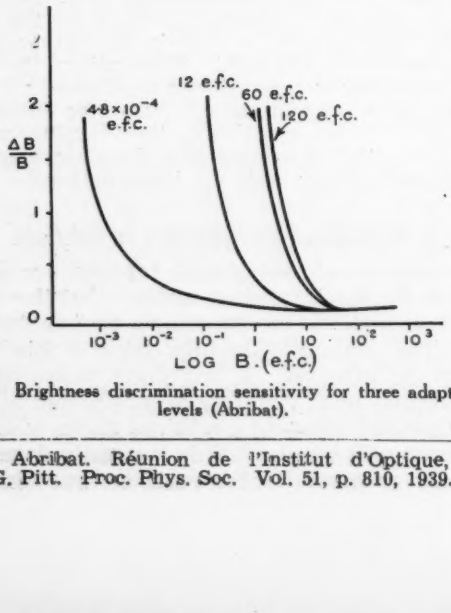

Fig 4. Brightness discrimination sensitivity for three adaptation levels (Abribat).

* M. Abribat. Réunion de l'Institut d'Optique, 1935. F. H. G. Pitt. Proc. Phys. Soc. Vol. 51, p. 810, 1939.

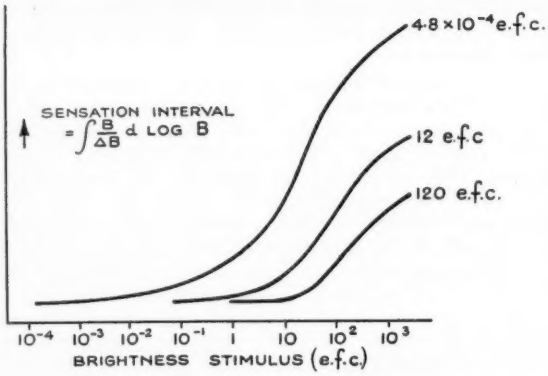

Fig. 5. Sensation stimulus relationship (Abribat).

showed the same general tendencies as those of Abribat and of Pitt.

A family of curves, which has been derived from a study of all the available data, appears to give a useful approximation to the characteristics of the eye. (Fig. 6.) These curves show that at any given adaptation level the Weber-Fechner law holds over a fairly limited range (i.e., those portions of the curves which are straight lines) and that at both high and low brightness levels equal ratios of stimulus no longer produce equal differences of sensation. This is, of course, in accord with practical experience. With such a family of curves, the problem of the quantitative study of contrast can be attacked.

6. Quantitative Study of Contrast.

(a) Contrast as a Function of Apparent Brightness Difference.

In order to employ the data of Fig. 6 for the quantitative study of contrast, it is assumed that the sensation of contrast produced by two contrasting brightnesses is a direct function of the difference in their apparent brightnesses. This assumption is reasonable for contiguous areas, but it may not be true for widely separated areas. Most problems are, however, concerned with contiguous areas.

Care has to be taken in using the numerical scale of apparent brightness. The scale is quite arbitrary, and has been so chosen that one unit represents a just perceptible brightness difference or contrast. It cannot, however, be assumed from this that a contrast of four units appears four times as great, or that in general that the scale is strictly additive. The numerical value of a contrast is an indication of the general order of that contrast. The scale will not necessarily discriminate accurately between two contrasts having nearly the same numerical value.

(b) Method of Assessing Contrast.

Most problems of contrast in illuminating engineering enquire either (a) whether the given contrast is greater or less than another contrast, or (b) whether the given contrast is adequate for the visual task. Both these forms of the problem can, in many cases, be attacked using the data of Fig. 6. Three values of brightness need to be known, i.e., the values B_1 and B_2 of the contrasting brightnesses,

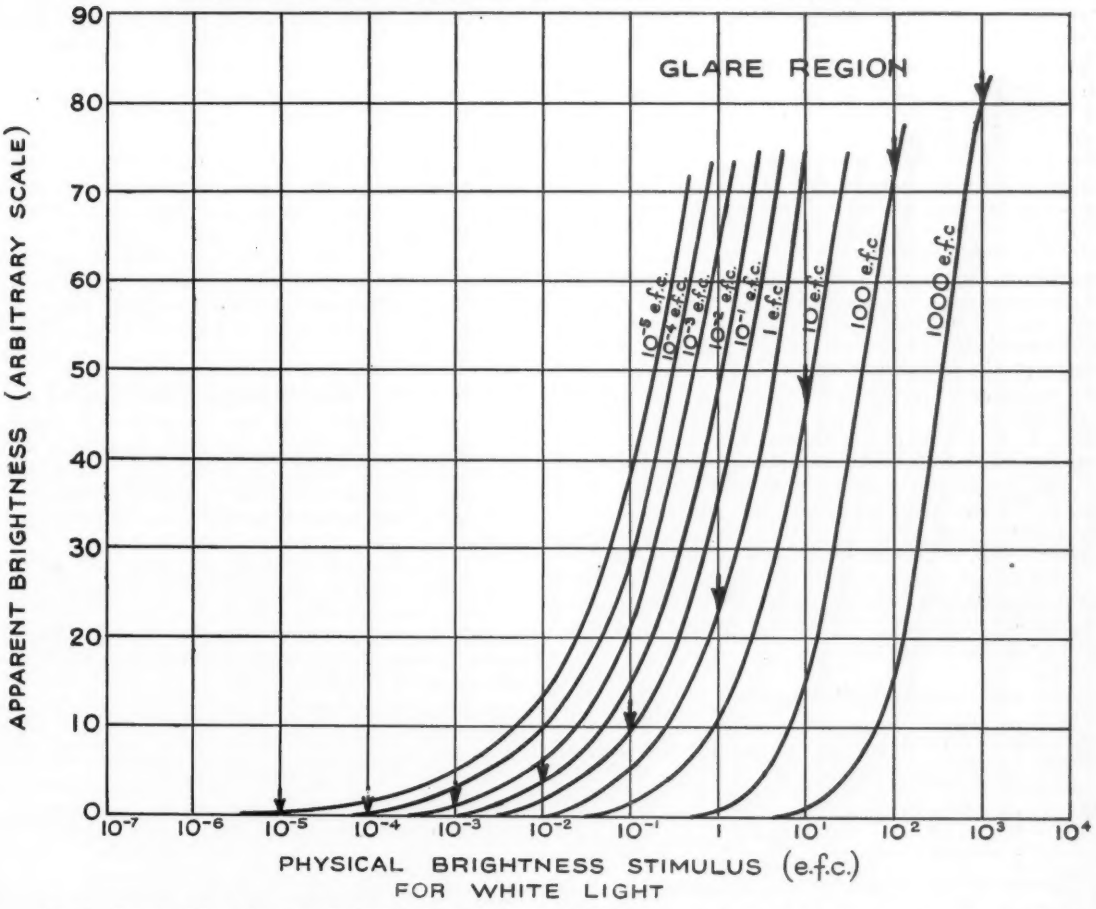

Fig. 6. Averaged data showing relationship between apparent brightness and physical brightness for adaptation levels from 10^{-1} e.f.c. to 1,000 e.f.c.

and the brightness B_3 to which the eye is adapted, which determines the curve in Fig. 6 to be used. Of these, B_1 and B_2 can be measured with a photometer, but the determination of B_3 is more difficult. Fortunately, as will be seen, for the order of accuracy of which the method is capable, the determination of B_3 to within $\pm$ 100 per cent. is usually sufficiently accurate.

In order to determine B_3, either an area can be chosen by inspection which appears to be of the average brightness of the scene, and the brightness of this area measured with a photometer; or else the vertical illumination falling on the eye of the observer can be measured (any very bright sources of light being screened off), and the average brightness of the scene calculated from the value obtained.

For example, suppose that the brightness of an object in a lighted street under peace-time conditions, is 0.1 e.f.c., and the background of the street is 1.0 e.f.c. The average brightness of the scene is of the order of 0.5 e.f.c. From the curve corresponding to 0.5 e.f.c. it is seen that at this adaptation 0.1 e.f.c. corresponds to an apparent brightness of 8 on the arbitrary apparent brightness scale, whilst 1.0 e.f.c. corresponds to an apparent brightness of 25. The contrast between these two objects is then taken as 25−8=17 arbitrary units. Now consider the same conditions reduced by 1:1000, which approaches blackout conditions. B_3 is then 0.0005 e.f.c., B_1 is 0.0001 e.f.c., and B_2 is 0.001 e.f.c. From the curve corresponding to 0.0005 e.f.c. it is seen that at the new adaptation, B_1 (0.0001 e.f.c.) has an apparent brightness of about 0.1, and B_2 (0.001 e.f.c.) has an apparent brightness of 1, the contrast now being 2−0.1=1.9 arbitrary units. This is very much less than the contrast under the brighter conditions, a result which agrees with experience.

In order to show that the estimation of B_3 is not critical, suppose that in the first case a 100 per cent. error had been made, and B_3 had been estimated to be either 1.0 e.f.c. or 0.25 e.f.c. In the first case the contrast between B_1 and B_2 would be found as 23—7

i.e., 16 units, and in the second case it would be 27—9 i.e., 18 units. The error is in neither case significant.

The contrasts obtained in this way can be compared one with another in the manner indicated, but care must be taken not to place too fine an interpretation upon the figures obtained. For example, whilst 17 units (see above) can be stated with certainty to represent a much greater contrast than 2.7 units, it would be making too great an assumption to state that the first contrast (of 17 units) was 17/1.9 =6.3 times as great as the second contrast (of 1.9 units). *All that can be expected of the method of assessing contrast is, that it will grade contrasts in order of magnitude more successfully than will a consideration of the physical brightness values alone.*

The consistency of the method can be estimated for one case in the following way. Dunbar* has obtained a relationship between the background brightness of a road surface and the brightness of an object seen against it, for the contrast between the object and its background to be just sufficient for a driver travelling at 30 m.p.h. to be certain of seeing the object. Since the criterion of contrast was the same throughout the range of background brightness investigated it would be expected that the contrast remained constant. Using his results and the data of Fig. 6, we obtain:—

TABLE 1.

Background Brightness (e.f.c.).	Object Brightness (e.f.c.) (from Dunbar).	Apparent Brightness Bgrd. (from Fig.6).	Object.	Contrast.
1.0	0.7	23 —	18	5.0
0.3	0.19	17 —	12	5.0
0.1	0.06	11 —	6.5	4.5
0.03	0.01	7.3 —	3.3	4.0
0.01	0	5 —	0	5.0

The values of contrast obtained are reasonably constant.

In each separate problem it is necessary to correlate values of contrast with the appropriate limit cases. For example, in the case of street lighting problems the data of Dunbar indicate that the minimum contrast between an object on the road and the background for a driver travelling at 30 m.p.h. to be certain of seeing the object is 5 units. Hence any contrast which under the relevant conditions is less than 5 units would be considered inadequate. In the same way the limit conditions for another visual task can be found by experiment, and contrast values obtained under test conditions compared with the limiting value.

In Fig. 6 an arrow attached to each curve indicates the adaptation brightness for which the curve is drawn. This again shows (see Fig. 3) that when the eye is adapted to moderately high brightnesses the sensation corresponding to this adapting brightness is in the middle of the range of sensations; brightnesses lower than the adapting brightness cause correspondingly lower sensations. But when adapted for low brightnesses the adapting brightness itself causes little sensation, and brightnesses less than the adapting brightness cause practically none. All that can be seen are brightnesses above the adapting brightness, which cause a disproportionately great sensation.

This can be seen well in a familiar effect in the black-out. On dark starlit nights the white painted indications, white lines, etc., stand out surprisingly and appear almost luminous. The general level of brightness of these white lines will be about six or seven times that of most objects present, and consequently they cause a sensation out of all proportion to that which they cause at higher levels. An example occurs below.

(c) Incorrect Measures of Contrast.

It has been pointed out in section 2 above, that contrast is a sensation, and that therefore it cannot be measured directly. The methods of section 6 (b) serve to obtain a grading of contrasts in order of magnitude, but are not necessarily a strict measure of contrast.

This grading of contrast is, however, very much to be preferred to any method of assessing contrast on the basis of the stimulus alone. All previous methods have, of necessity in the absence of any physical brightness—apparent brightness data, been measures of stimulus only.

Previous measures of contrast have been usually based on:—

(1) $\frac{B_1}{B_2}$ the brightness ratio, or

(2) $\frac{B_2-B_1}{B_2}$ i.e. $\frac{\triangle B}{B}$, the relative brightness difference.

The function

(3) B_2-B_1 has been used by Stiles, who is always careful to describe it as a brightness difference; it is sometimes misquoted as implying a "contrast."

The first measure, i.e. the ratio of the contrasting brightness, will give an approximately correct grading of contrast when (i) the contrasting brightnesses are of the same order as the average brightness of the scene, and when (ii) this average brightness is between about 1 e.f.c. and 1,000 e.f.c. For conditions of low brightness, or when the contrasting brightnesses differ much from the adapting brightness, the errors involved may be very great. For example, the contrast between brightnesses of 10 e.f.c. and 100 e.f.c. at an adaptation level of 100 e.f.c. would, by (1), be the same as between 0.001 e.f.c. and 0.01 e.f.c. at the same adaptation level, whereas in fact the latter contrast would be imperceptible.

The second measure, $\frac{B_2-B_1}{B_2}$, will give a correct grading of contrast under the same conditions as the first measure. Both depend, of course, on a logarithmic relationship between physical brightness and apparent brightness. Such a relationship is known to hold over a limited range, as evidenced by the parts of the curves of Figure 6, which are approximately straight lines. Over this range, a given ratio

* Trans. Illum. Eng. Soc (Lond.) 3, 187-195, Dec., 1938.

of physical brightness always produces the same difference in apparent brightness.

The third measure, B_2--B_1, gives a rough grading of contrast *for a given adaptation level*, but even under constant adapting conditions the grading fails to discriminate contrasts correctly in the ranges where methods (1) and (2) above are reasonably close.

All such measures of contrast which do not take into account the adaptation level are, therefore, liable to considerable error, especially for all work concerned with low brightnesses.

For example, consider four juxtaposed brightnesses of 1, 10, 100 and 1,000 e.f.c. viewed as an adaptation level of 100 e.f.c. The contrast between each and its neighbour measured by the three methods above, and by the method of section 6 (b) is given in the Table 2 below:—

TABLE 2.

Brightness (e.f.c.)		B_2/B_1	$(B_2-B_1)/B_2$	B_2-B_1	Contrast by apparent brightness method.
A	1	10	0.9	9	11
B	10	10	0.9	90	57
C	100	10	0.9	900	51
D	1000				

The three contrasts A-B, B-C, and C-D are represented as equal by the measures B_2/B_1 and $\frac{B_2-B_1}{B_2}$; the measure B_2-B_1 would suggest that the contrast A-B: B-C: C-D: : 1:10:100. Visual inspection demonstrates immediately that none of these measures approaches the truth. The contrast by the apparent brightness method is assessed as A-B: B-C: C-D: : 12:57:51, which is in good accord with the visual impression.

If now all the above brightnesses are reduced by 1/1000, so that four brightnesses of 0.001, 0.01, 0.1 and 1 e.f.c. are viewed at an adaptation level of 0.1 e.f.c. the "contrasts" between each brightness and its neighbour are:—

TABLE 3.

Brightness (e.f.c.)		$_2/B_1$	$(B_2-B_1)/B_2$	B_2-B_1	Contrast by apparent bright ness method.
A	0.001	10	0.9	0.009	2
B	0.01	10	0.9	0.09	7
C	0.1	10	0.9	0.9	26
D	1				

Whilst the measures B_2/B_1 and $\frac{B_2}{B_2-B_1}$ still give the same values of "contrast" as before, B_2-B_1 suggests very much smaller contrasts, whilst the method of apparent brightness indicates that contrasts A-B and B-C are much less than previously, whilst contrast C-D is not reduced to such a degree. Only the apparent brightness method is in accord with visual inspection.

If the scale of the experiment is now further reduced by 1:1000, to bring the brightnesses to within the range of night vision, the contrasts are as follows, the adaptation level now being 10^{-4} e.f.c. (corresponding to weak moonlight).

TABLE 4.

Brightness (e.f.c.)		B_2/B_1	$(B_2-B_1)/B_2$	B_2-B_1	Contrast by apparent brightness method.
A	0.000001 (10^{-6})	10	0.9	0.000009	0
B	0.00001 (10^{-5})	10	0.9	0.00009	1
C	0.0001 (10^{-4})	10	0.9	0.0009	4
D	0.001 (10^{-3})				

The measures B_2/B_1 and $\frac{B_2-B_1}{B_2}$ still give the same as before, which is obviously incorrect, whilst B_2-B_1 yields values of the wrong order, relative or absolute. The apparent brightness method, however, again accords with visual inspection, in showing that the contrast A-B is now imperceptible, that B-C is just noticeable, and that C-D is relatively prominent.

These last two conditions again illustrate the effect already mentioned. The contrast C-D is so much greater than the contrasts A-B and B-C that the brightness D appears to stand out prominently from the rest. At higher brightness levels, as shown by Table 2, however, the contrast C-D is actually *less* than the contrast B-C, because the brightnesses approach the glare region.

It is obviously legitimate (although not always useful) to express the *stimulus* conditions as

$$\frac{B_1}{B_2} \text{ or } \frac{\triangle B}{B}$$

or some other function of the brightnesses concerned; but it is desirable that such functions should be described accurately for what they are—as for example brightness ratio, or relative brightness difference, etc.—and not as "contrast" which they often are not. This will avoid much of the confusion which at present exists.

7. Contrast Phenomena in Practice.

It is interesting to note how many of our daily actions can be attributed to the effects of contrast. For example, sitting with one's back to the window at an interview has a twofold effect. The interviewer's face is in shadow, and the background to it—the window—is bright. The person being interviewed is therefore looking with eyes adapted to a high brightness, at a not too well illuminated face, the brightness of which is nearer the lower end of his range, so that he can see little of its detail. His own face, however, receives higher illumination, and is seen against a comparatively dark background; its brightness is near the middle of the range of the interviewer's eyes. All the details of the face and changes of expression are enhanced for one person and diminished for the other.

Many familiar devices for making things conspicuous operate by increasing contrasts. A cricket bowling screen, the white screen behind certain railway signals, the black, white, and red of surveyor's station poles, the soldiers' elementary rule of avoiding the skyline, are all obvious examples. The use of white paint on kerbs and obstructions is another, the value of which has increased in the black-out for

the reasons already explained. The importance of contrast in vision in lighted streets and by headlights needs no emphasis.

In industry it is necessary to avoid glare, either direct or reflected, because glare " makes seeing difficult "; this we had learned by experience. The curves on Fig. 6 show some of its effects. Glare increases the adaptation level of the eye so that a given brightness difference may produce a less sensation of contrast. (This is, of course, only one of several manifestations of glare.) On the other hand, for a given *ratio* of brightness between two objects the higher the absolute value the greater the contrast, within quite wide limits. Therefore the higher the illumination, in general, the better we see. This also can be seen from Fig. 7.

The problem of enhancing contrasts for inspection, particularly for metal surfaces, is frequently that of applying the simple laws of reflection.*

Surprisingly enough these laws are often difficult to apply in practice, because the best answer may demand a costly double or triple inspection; but the lighting engineer cannot be blamed for this.

An interesting example of a fairly straightforward problem is that of razor-blade inspection. Among the many tests to which modern safety razor blades are subjected is the visual inspection shown in Fig. 7. A powerful light is directed on to the edges of the blades, which are arranged to lie parallel with one another, the blades being a little out of the vertical. A good edge, being very sharp, will reflect so little light to the inspector's eyes (obeying the laws of specular reflection) as to appear almost black. A flaw, on the other hand, will diffuse light over a considerable angle, and generally appears a contrasting grey. A tray of blades, having a large percentage of flaws, is shown in Fig. 8 as it would appear to the inspector, with the general arrangement shown in Fig. 7. To locate all the faults it is necessary to repeat the inspection with the tray turned through 180° and the blades reset so that they assume the same angle to the light as before, the reverse side now facing the inspector. The background to the lighting system must be dark.

Fig. 7. General arrangement for inspection of razor blades.

* W. R. Stevens and S. Anderson, Trans. Illum. Eng. Soc. (London), Vol. III., No. 1, Jan. 1938.

Perhaps the most remarkable application of contrasts and their behaviour is the portrayal in a picture having two dimensions of objects having three dimensions. Several aspects of this have already been discussed. Presumably, it is possible because in practice the eye perceives depth only by inference and not directly; it distinguishes directly only differences of brightness and colour over various directions in space.* If these can be simulated in a picture or photograph, the visual sense is reminded of the brightness and colour distribution of the original, with a vividness depending upon the faithfulness with which the brightness and colour distribution is reproduced.

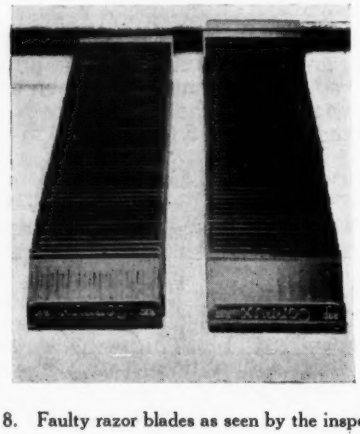

Fig. 8. Faulty razor blades as seen by the inspector.

It has been emphasised that geometry is perhaps the most important single item in recognition. It is not only the geometry of the outline of an object, but also that of the detail within the boundary. For example, a change of shadows within a face can alter the expression completely. This is the main device on which an actor's make-up depends. Until comparatively recently, an actor would treat his face rather as a blank canvas on which most of the shadows had to be painted, for the " flat " lighting usually adopted cast very few shadows. This is altered somewhat to-day, for modern stage lighting technique is able to introduce shadow contrasts, and therefore interest in a way which was impossible with earlier and cruder apparatus.

Contrast may create interest, but one of the most important war-time applications of contrast effects is camouflage, which is, of course, the craft of " not attracting interest." When a building is camouflaged it cannot disappear completely, but it may become so inconspicuous in relation to its surroundings, that an

*At close ranges accommodation, convergence, and the stereoscopic sense also assist in the inferring and estimation of depth, but their effect is surprisingly small.

observer does not notice it—although if he does notice it, it may seem as easy to see as before the camouflage was applied.

The illuminating engineer may divide the processes of camouflage into three:—

(i) Camouflage by reducing contrasts.

(ii) Camouflage by introducing artificial heavy contrasts which conflict with the true geometry of the object (disruptive camouflage).

(iii) Camouflage by introducing artificial contrasts similar to those associated with a different object (imitative camouflage).

The most familiar example of type (i) is the khaki army uniform, which "blends well" into a variety of landscapes (i.e., produces small contrasts with its usual backgrounds). The camouflage consists of a more or less uniform colour, matching as nearly as possible that of the surroundings. The arctic fox, which in winter changes its coat to pure white, is a good example from nature; the camel matching the colour of the desert sand is another. From modern military practice, apart from khaki uniforms, there are the "duck-egg blue" colour on the undersides of some day aircraft to match the sky, and the grey of warships, which is varied according to the part of the world in which they are operating.

If this type of camouflage is applied to fixed positions the natural surroundings may be altered in appearance according to the time of year. Therefore, if a building is well camouflaged in summer with greens it may require russet browns in autumn and greys and whites in winter. The colours which made it inconspicuous in one season may enhance the contrasts in another. So this type of camouflage needs attention to keep pace with the changing appearance of the countryside.

Disruptive camouflage aims at breaking up the *outline* of the object by large areas of colour, arranged so that they produce geometrical patterns which conflict with the true geometry of the building and its shadows. The effect is to produce a building really quite easy to see, but hard to recognise. Examples are so common that it is unnecessary to go into details. In nature it occurs in animals, such as the tiger, the zebra, and the leopard. The size of the patches must be comparable with that of the outlines which they are intended to confuse. If they are too small they will themselves become inconspicuous before the building does when viewed from a distance.

By the third method of camouflage (imitative camouflage) the building is made uninteresting by introducing contrasts associated with something else. A factory becomes a row of houses; a machine-gun post a hayrick. The idea behind the method is obvious; its application often complex. The method also occurs in nature, for example, in the "stick insect," which looks like a twig. It has the advantage of not needing to be changed to match changing surroundings as often as the other types of camouflage.

8. Conclusion.

This paper has described some of the first principles of sight and has applied them to a few simple cases. They have necessarily been greatly simplified; and in simplifying them there is a danger of supposing that the matter has been nearly exhausted and that little remains to be learned.

The physics alone are extraordinarily complex. Each of the myriads of points which make any scene is reflecting radiation with an individual distribution in all directions in space: the energy is radiated on a whole spectrum of frequencies, the spectral distribution varying from one point to another, and even for any one point varying often with the direction of reflection. Then the whole of this complex of radiation varies with time.

A minute fraction of it enters the eyes by two apertures a few millimetres in diameter; and in a fraction of a second it is analysed and classified, as to its directions, its intensities, and its spectral distributions, and this vast information is passed on so quickly that we can follow easily its variation with time. It is a system of analysis and classification surpassing anything else in Nature.

But even the physics are less wonderful than the interpretation of the information. From it we deduce continuously form, motion, size, distance, texture, material, position, of many objects at once; age, character, expression, behaviour: almost all that we know of everything that we cannot touch. In the end, most of the material for our imagination, art and beauty, come in the same way.

Our best experiments are crude by comparison; we have touched but the fringe of the matter, and we can only stand in awe of so marvellous a mechanism. Yet without some understanding of seeing we cannot begin to serve our sight, which is the proper business of illuminating engineering.

DISCUSSION

Dr. W. D. WRIGHT, in opening the discussion on contrast, agreed with the authors as to the complexity of vision and, at the same time, the extreme simplicity of the act of seeing. It was this that made the problem of scientific investigation so difficult. If one desired to investigate one little phenomenon of vision it was necessary to isolate it and do some experiments which were really completely outside the normal scope of seeing and the normal problem encountered in practice. It was very difficult for those engaged in visual research work to relate their results to illuminating engineering problems. He further agreed with the views already expressed as to the importance not only of seeing contrast but of being able to interpret what was seen. Although that was very much a matter of common sense it needed to be pointed out. As an instance of this, he mentioned that on one occasion recently when he was driving along a more or less country road and following the white line, the white line seemed suddenly to bend off to the left. He subsequently recognised that it was the mark of a cart wheel

which had left its track on the road, but a moment or two had elapsed before he recognised that this was so. Another example of the same kind of thing, indicating the need for being able to recognise what was being seen, occurred when, in driving along a road, one approached a bridge. Very often there was nothing to indicate that one was approaching the bridge, and a driver wondered what he was coming up against in the dark. Personally, he had the impression that he was running into a brick wall. Therefore, those concerned with black-out lighting should aim at throwing up the shadows and arranging contrast so that such objects could be recognised as easily as possible.

Dr. K. NORDEN, referring to shadows, which were one of the phenomena in contrast, remarked that shadows which were revealing could be still further emphasised. There were several types of revealing shadows: those which were cast by the objects themselves might indicate the height and width of the objects, or there might be extraneous shadows cast on the objects, thereby revealing their form and shape. There were also background shadows, which brought out the objects in relief; and, finally, the shadings modelling the surface and giving a plastic view of the object. By discriminating between these different forms of shadow it was possible to make good progress towards the elucidation of shadow technique, and he suggested that the deliberate application of shadows to illuminating engineering with a view to promoting a better plastic view of an object was a direction in which work should be carried on.

Mr. L. G. APPLEBEE said he had enjoyed the demonstrations given by the authors probably particularly because in his branch of illuminating engineering contrast was used very much indeed. It had been necessary to study this problem in the theatrical profession for the reason that the scenic artist painted his scenes by average daylight, and the problem was how to make it look natural when it was lighted artificially and perhaps only by a row of lights. This was done by contrast, some examples of which had been so ably shown by the authors. It had been interesting to hear what could be done by a little bit of make-up, but the effect desired could not be obtained by make-up alone. There must be contrast in the lighting, and that was why, as had been said, in such a play as the "Vagabond King," they used as many as forty incandescent spot lights to provide the necessary contrast to give realism on the stage and to take the flatness out of the scene. Actually, forty incandescent spot lights for this purpose was a relatively small number, for in one New York theatre they used no fewer than ninety-five, of varying intensities, up each side of the proscenium.

Dr. J. W. T. WALSH referred to the contrast presented in a coloured scene, and said that it used to be—and probably still was—one of the difficulties of painters that the colours were obtained very largely by subtraction. If, for instance, green was obtained by mixing blue and yellow pigments, the available reflection factor of the mixture was quite low, and if one tried to get back the contrast by toning down whites and the simple colours the whole thing became so dark that a Rembrandtesque effect was produced. The only way out was to use a transparency, and could the authors say anything as to the possibility of getting something tolerable in the way of contrast reproduction by the use of a transparency?

Mr. J. S. Dow approved the principle, endorsed by the authors, of confining the use of the term "contrast" to the sensation created. In the past some confusion had been caused by authors selecting one or other of the numerical expressions involving brightness of object and background as the basis of their investigations and labelling this "contrast." It seemed much better to use the terms "brightness ratio," "brightness difference," etc., as the authors had done. It would be agreed that none of these numerical expressions could furnish a correct estimate of contrast in all circumstances. It might be helpful, however, if the authors could indicate which of them, on the whole, came nearest to doing so.

Referring to the picture of Durham Castle, which had been exhibited, Mr. Dow said that the loss in contrast with diminishing illumination was very evident. Was there, however, an upper limit—apart from discomfort glare—at which contrast again began to suffer, and was this within the range of brightness likely to be encountered in practice? The danger of approaching this limit was possibly greater in the case of transparencies. He understood that excessive contrast might prove a drawback in film work, and that on occasion it had been proposed to alleviate this defect by superimposing a weak general illumination (sometimes in colour) over the whole picture.

Reference was made to the important possibilities of fluorescence in pictorial effects, as it increased substantially the available brightness range, limited to about thirty to one in the case of pigments. In certain cases, for instance, in depicting gleaming metal,

a very much more lifelike effect could thus be produced.

In conclusion, he wished to point out the advantage secured by using white materials of high reflecting power in preference to a "dirty white" in the blackout, in order to render objects easily visible. In his experience there was a somewhat unaccountable gain in apparent brightness as one approached the limits of reflecting power obtainable from a dead white surface—a marked difference, for example, between 80 and 90 per cent.

THE PRESIDENT, referring to a slide of the field of a Lummer-Brodhun photometer, which had been shown by the authors, said he wondered if anybody else had noticed what he thought he had, viz., that in looking at the field under low illumination it was not possible to see the contrast, but if one looked away to the edge of the screen the contrast was quite marked. These effects were probably due to a difference in the response of the outer field of vision to that of the centre of the field.

In another slide were shown four contrasts, viz., 1, 10, 100, and 1,000, but even a trained observer might think that each patch was not uniformly bright. Similarly, in portraiture photography, the difference between the actual and the apparent contrast was of great importance.

Mr. A. MANSELL said he had been hoping the authors would say something about the relationship between speed of vision and contrast. For instance, supposing one were looking at a common or garden haycart on a sunny day, and the cart was moving at four miles an hour and a person was walking alongside one of the wheels. With the sun in a certain direction, a sharp shadow would be thrown to the inside of the wheel and it would be possible to see the wheel and the spokes in distinct contrast to the roadway. If, however, the cart was moving much faster, and a person was cycling alongside, it would not be possible to see the spokes of the wheel clearly.

Conversely, if one took a piece of ordinary cinematograph film and passed it through a projector slowly the contrast on the screen would be of a particular order, but one would see a mass of colour or contrasts which meant nothing. If, however, the film was passed through at the proper speed a very different effect was obtained. He would like, therefore, to hear some explanation of the relation between contrast and speed of vision, if any.

Mr. L. G. APPLEBEE pointed out that, although in passing through the projector the film was continually moving, it was actually stationary for a fractional part of the time, and that was when the audience saw it on the screen. When the film moved a shutter passed over the lens, so the audience were always looking at a large number of "stills."

Dr. NORDEN, referring to the point made by the President as to the lack of uniformity in the brightness of the field in the slide showing the four degrees of contrast, suggested that this effect was due to marginal contrast, an effect set up mainly along the border-line between adjacent surfaces of different brightnesses.

THE AUTHORS, replying to the discussion, agreed with Dr. Norden about the importance of shadows in the revealing of objects. They were not completely in agreement with Dr. Wright that it was always necessary, in order to investigate a given phenomenon of vision, to isolate it outside the normal scope of seeing. They believed that for the illuminating engineer, at any rate, it was almost always desirable to set up an experiment as nearly as possible under actual conditions of practice. It did not follow that this procedure failed to disclose the underlying fundamental laws governing vision under those conditions, and their own experience had been to the contrary.

The terms "brightness ratio" and "brightness difference," quoted by Mr. Dow, were measures of stimulus only and not of contrast, which was a sensation. Over a very limited range the brightness ratio

$$\frac{B_2 - B_1}{B_2}$$

gave a better measure of contrast than other terms, but as had been shown in some greater detail in the written paper, the only satisfactory assessment of contrast was by the use of the apparent brightness method. This method demonstrated all the phenomena of contrast which Mr. Dow had described, and explained particularly the extraordinary visibility of white objects under black-out conditions. A small increase of reflection factor could be seen from the curves of Fig. 6 to produce a disproportionate increase in contrast, because the slope of the contrast curve was increasing very rapidly. These curves also showed that there was, as Mr. Dow had suspected, an upper limiting brightness where the contrast again deteriorated. This often occurred in practice. For example, it was often impossible to see variations in brightness over the surface of an opal diffusing fitting without the aid of a neutral filter or until the eye had had time to adapt.

They would have preferred that Dr. Spencer should

have answered Dr. Walsh from his much greater knowledge of colour reproduction. The answer presumably turns upon the efficiencies obtainable from reflecting and transmitting pigments available for making the picture. The painter does not necessarily work from a three-colour palette, and his greens are not usually obtained by mixing yellow and blue as Dr. Walsh suggested; if he can, by a suitable choice of pigments, retain a reasonably high general reflection factor in the highlights of the picture, there is no reason why the reflecting picture should be at a disadvantage—except the inherent one that a transparency must always have special lighting, which can therefore be properly arranged, while the reflecting picture does not demand special lighting and does not always get sufficient illumination.

Other points which had been raised had mostly been already answered in the discussion.

The authors wished to express their indebtedness to Dr. Spencer, Mr. Chanon, Mr. Gaseltine, Messrs. Ever-Ready Razor Company, Ltd., Mr. Penny, and Mr. Wilson for the loan of photographs and apparatus used in demonstrations at the reading of the paper, and to Mr. Pelerin and his assistants for their help in preparing them.

APPLICATIONS FOR MEMBERSHIP.

Elections Pending.

The names of the following applicants for membership were presented for the first time at the meeting held on April 8, 1941:—

CORPORATE MEMBERS:—

Cooke, K. J. R. .....104, Dunchurch Road, RUGBY.
Dodgson, J. S. .....17, Wensley Road, LEEDS, 7.
Holtby, R. .....14, Norfolk Square, Hyde Park, LONDON, W.2.
Rogerson, J. N.....92, Elm Lane, BRADFORD.
Tattlet, J. .....23, King Edward Avenue, Horsforth, LEEDS.

COUNTRY MEMBER:—

Fielding, C. .....16, Hall Road, HEBBURN-ON-TYNE.

Elections Completed.

The following applicants, read at the previous meeting on March 11 for the second time, were formally declared members of the Society at the meeting on April 8:—

CORPORATE MEMBERS:—

Clery, A. Agar.....36, Grosvenor Gardens, LONDON, S.W.1
Davis, Basil .....21, Eaton House, Upper Grosvenor Street, LONDON, W.1.
Eades, E. C. ....."Valhalla,' Marlborough Avenue, Bromsgrove, WORCS.
Pellow, C. H.....25, Rochlands Drive, Kenton Lane, Stanmore, MIDDX.
Thompson, D. M. .....City of Manchester Gas Department, Medlock Street, MANCHESTER, 15.

ASSOCIATE:—

Lacey, T. A. .....51, Portland Road, Kings Heath, BIRMINGHAM, 14.

COUNTRY MEMBERS:—

Douglas, J. T. .....41, Granville Drive, Forest Hall, NEWCASTLE-UPON-TYNE.
Jones, Llewellyn .....24, Whalley Grove, Whalley Grange, MANCHESTER, 16.
Lockwood, C. H. .....68, Topping Street, BLACKPOOL.
Macartney, H. ....."Woodville," 64, Wilmslow Road, Cheadle, CHESHIRE.
Strachan, D. A. .....Metropolitan Vickers Electrical Co., Ltd., Metro-Vick House, Northumberland Road, NEWCASTLE-UPON-TYNE.

Elections Completed.

The list of applicants for membership whose names had been presented at the previous meeting on February 11 (Trans., Vol. VI., No. 2, p. 36) was again presented, and these gentlemen were formally declared members of the Society.

TRANSFERENCES FROM COUNTRY MEMBERSHIP TO CORPORATE MEMBERSHIP:—

Bolt, J. N. .....290, Worsley Road, Swinton, LANCS.
Holmes, J. G. .....21, Fitzroy Avenue, Harborne, BIRMINGHAM.

I.E.S. FELLOWSHIP.

Applications for Fellowship on behalf of the following have been accepted by the Council:—

Crisp, H. D. .....The General Electrical Company, Ltd., 12, Battery Road, SINGAPORE.
Ette, F. S. .....103, Dove House Lane, Solihull, WARWICKSHIRE.
Gillespie-Williams, R.....61, Zulla Road, Mapperley Park, NOTTINGHAM.
Herbert, George .....25, Duke Avenue, Muswell Hill, LONDON, N.10.
Imrie-Smith, W. .....17, Bush Court, Cran Lane, SOUTHGATE, N.14.

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INDUSTRIAL LIGHTING FOR WAR CONDITIONS

By R. MAXTED, B.E., A.M.I.E.E., F.Inst.P. *(Fellow)*

Paper presented before the Local Centres in Birmingham (October 11), Leeds (October 14), Glasgow (October 16), Manchester (October 17), and Nottingham (January 31, 1941).

"To see with one's own eyes, to feel and judge without succumbing to the suggestive power of the fashion of the day . . . . . ."—EINSTEIN.

Everyone concerned with industrial lighting is aware that great changes in factory lighting practice have become essential and are already in progress. Certain defects in peace time practice are magnified by war conditions, and impose on human efficiency a limit which cannot be tolerated when efficient factory production is of such vital importance.

It is unfortunate that lighting reforms, such as make a further temporary demand upon production facilities, should be necessary during this period. That such reforms are accepted as essential safeguards to production is confirmed by the action already taken by various Government Departments, and in particular by the Ministry of Supply. Factory lighting is recognised as a factor commonly exerting a restraining influence upon industrial output, and as a national problem it calls for action and expenditure on a national scale.

In these circumstances it may well be asked whether the true significance of artificial lighting, not merely as a means of making work possible, but as a positive factor capable of raising normal industrial efficiency to a new level, has yet been presented.

It is doubtless true that the reforms in lighting needed immediately in large sections of industry can be met to a considerable extent by the proper use of conventional standardised equipment. In large numbers of factories the mere level of illumination is inadequate, and the effect of the "six foot-candles" recommended in the fifth Report would be profound. Yet even the adoption of the I.E.S. "recommended values" leaves untouched the question of *quality of lighting,* the importance of which has been greatly accentuated by application of artificial light to 50 to 100 per cent. of working hours—as compared with 10 to 15 per cent. in time of peace.

Experience of war-time lighting leads to the belief that no other single factor has a more decisive control of the health and efficiency of operators, and that in the more vital work at least new methods and new equipment are needed. There is, however, a natural tendency to persevere with methods and practices developed under peace conditions. Manufacturers are apt to be influenced by the considerations that stocks of certain designs, well suited to mass production, are available; that press tools already exist for further manufacture; and that some types have survived because of their apparent cheapness.

Certainly our skill in economic production must be exploited to the full in undertaking so vast a programme as the relighting of our factories. The choice of methods should not, however, be determined solely by convenience in manufacture of equipment, but by the extent to which such methods are adapted to a wartime lighting schedule. Investigations show that a compromise between cost and quality which may have been reasonable in peace time often amounts in war time to a neglect of suitability, and even in some of the better lighted factories efficiency is seriously affected.

The real issue is industrial efficiency at a proper cost, not the provision of adequate foot-candles at a minimum cost, irrespective of the war-time importance of quality of lighting. Expenditure on reform in industrial lighting, though intrinsically great, can be but a small fraction of the total expenditure on national industrial effort, and should be assessed in terms of its effect on production. Loss of output is the real cost of defective lighting, and in this sense factory lighting may be regarded as a production tool capable of a development not yet generally appreciated.

Industrial Health and Efficiency

In factories subjected to an almost complete and continuous black-out, it is obviously important to ensure that the artificial lighting releases the full natural ability of the operative. But efficiency is also governed by health, and it is essential to avoid lighting defects which, *in prolonged operation,* may degrade vision and health or undermine psychological robustness.

Experience has shown that a few months' work in a blacked-out factory may result in marked deterioration in physical and nervous condition—a waste of vital human assets which the nation cannot countenance. Faulty lighting produces eyestrain, which in turn causes nervous disorder, and the Lighting Engineer has a greatly increased responsibility for industrial health when the eyes are denied lengthy recuperative periods in natural daylight.

There is a further consideration which cannot be

ignored—the psychological advantage of securing a natural and cheerful appearance in the factory, especially by day. Artifical lighting often emphasises the unnaturalness of a daytime black-out, but it *can* be designed to contribute enormously to psychological welfare. Yet the greatest emphasis must undoubtedly be placed upon protection from eyestrain because this quickly produces a state of general debility where purely psychological factors assume unwonted and formidable proportions.

To gauge truly the potentialities of factory lighting the engineer must gather his experience with the factory worker, plan with the efficiency engineer, work with the welfare officer, and think with the ophthalmologist and the psychologist. He must see with the hard-worked eye of the operative, and not with the untried eye of the casual observer who can sometimes put the glitter and even the glare on the credit side as contributing to the "brightness" of a shop.

Development—Statutory and Technical.

Now that industry has passed from one war to another without putting factory lighting in a condition to withstand the searching strain of war it may be helpful to consider briefly the developments of recent years. Two aspects may be considered—that showing the gradual progress of factory lighting towards recognition as a national problem, and marked by a sequence of reports of Departmental Committees; and that consisting of the commercial and technical development.

Reports containing recommendations have been issued by Departmental Committees in 1915, 1921, and 1922. The existing committee was appointed in November, 1937, and presented the Fourth Report in September, 1938, and the Fifth in June, 1940. From these dates alone emerges a connection between war conditions and the need of reform.

The lack of legislation and the persistence of reports after twenty-five years seem to give a clue to the fundamental difficulty—lack, not of purpose, but of convincing technical proposals. Some have assumed that the solution lay in providing sufficient and uniform illumination at the working plane, coupled with recommendations in regard to the avoidance of direct glare. Others have felt that these two requirements did not suffice to define lighting of high quality and that other factors were of equal importance.

Although practical efforts were made to reduce source brightness and to improve colour rendering, high quality lighting did not appear economically justifiable in the pre-war years. Attention was therefore concentrated mainly on the production of prescribed values of foot-candles in the least expensive way possible, and the I.E.S. "Recommended Values" came to be regarded as a code though never intended as such.

The natural result of this conception of industrial lighting has been the development of overhead systems in which efficient, brilliant, and powerful sources were widely spaced in formal patterns, irrespective of the positions of plant and operatives on the floor area. In short, technical development was directed towards the economical attainment of higher illumination, but was not effectively controlled by considerations of "suitability," the importance of which was not so obvious in peace time.

It is instructive to observe that throughout the series of reports of the Departmental Committee on Lighting in Factories and Workshops, a distinction has been drawn between "adequacy" and "suitability."

If lighting is proper and befitting, as the term "suitability" implies, then inherently there must be an adequate quantity of light. Surely this segregation merely emphasised that until "adequacy" was attainable in general practice, the other factors could not usefully be investigated.

Advances in the lighting field, together with the changed viewpoint arising from war conditions, have already led to the conclusion that "adequacy" is economically justified—as is illustrated by the bold step taken in the Fifth Report of advocating a minimum of 6 ft.c.

It seems clear that there has been a considerable shift in the economics of factory lighting and that the earlier view was too narrow for war conditions. Under these circumstances, adequacy must be viewed in proper perspective, as one of several equally important characteristics of suitable lighting, and thought should be given to means of defining and achieving suitability.

Evaluation of "Suitability."

When a quality is to be realised in practice it is expedient that it should be clearly understood and precisely defined. There are some who are able to assess conditions in terms of fundamental principles and to express the conclusions they reach in a definite form. Others, however, are at a loss unless these principles can be presented numerically.

The lighting engineer when called upon to deal with "suitability" in industrial lighting is apt to seek

a solution on this basis; but his success in doing so is limited by the complexity of the problem, associated as it is with vision and psychology—fields where qualitative analysis is in its infancy and quantitative data are conspicuous by their absence. Even if, by qualitative study, he is able to form a just conception of the essentials of suitability, and to devise methods of achieving these with fair success, he cannot readily provide objective proof of their value, such as can be set against increased expenditure. This was the position in the years preceding the war. The conditions of stress since experienced have, however, enabled the effect of unsuitable lighting to be demonstrated in practice. The improved condition and performance of operatives, following the removal of fundamental defects in methods of lighting, have illustrated the practical value of suitability and the remarkable latent recuperative powers of the human system.

Misunderstanding has been caused in the past by the prevalent impression that eyestrain is due to fatigue, instead of being one of the main causes of it —a truth which will be readily affirmed by those who have had the misfortune to spend a day without the glasses on which they are accustomed to depend Glasses cannot, however, eliminate the strain due to defective lighting. The introduction of lighting of high quality can rapidly disperse, not only eyestrain, but also obvious physical and nervous strain which must therefore be attributed to unnatural visibility.

Improvement in health and efficiency can be shown in some classes of work by figures for output and spoilage. Owing to the simultaneous influence of other variable factors, however, such figures are seldom suitable for use outside the particular factory to which they apply. They do not furnish a fair means of recording or evaluating suitability of lighting, which should be regarded as a subject for personal investigation and for practical demonstration.

Defining Suitable Lighting.

In planning, and especially in discussing, an investigation it is an advantage to define the aims, provided always that the pitfalls and the probable limitations of a definition are borne in mind.

Suitable lighting may be described as lighting which reveals the work in such a way that the natural ability and efficiency of the operative is not restricted by the lighting conditions; that the operative is not conscious of any limitation in the lighting; and that he is not subjected to strain—physical, nervous, or psychological—due to any effect of the factory lighting conditions as a whole.

This is a general description of suitability within the meaning of the present need for lighting reform. Having regard to the complexities of the subject, such a definition must necessarily be general, but the problem can be further defined by reference to some of the common lighting defects which it appears necessary to avoid.

It must be remembered that illumination that is adequate when properly applied may be quite inadequate where the lighting is otherwise unsuitable. Positioning of the light source relative to the work and the operative is very important, and there can be little doubt that in many classes of work suitability has been sacrificed for the economy of a general system of large sources widely spaced in formal pattern.

Another effect, which is sometimes properly and wisely exploited in special visual tasks, is due to the reflection of light sources in material of a polished or specular nature. There is seldom, if ever, any advantage in this effect when the light source has a high brightness. Where the effect is deliberate, as in the inspection of tinplate, a source of large area and low brightness is used.

In most cases, the reflected glare of bright sources is a very serious handicap to the operative, and in a very short period of work it can cause considerable irritation and strain due to the strenuous efforts made to perform the visual task. When numerous overhead sources are involved, the operative cannot eliminate reflected glare, although he often attempts to do so by continually changing his own position and that of his work. Thus, there is waste of time and energy due to unnecessary operational motion, and there is spoilage caused by faulty visibility. With prolonged working, reflected glare is the most fruitful source of eyestrain and of damage to vision.

Apart from ruining the local field of view, the reflection of bright sources affects the general field of view where this contains many polished surfaces. Thus many working areas, especially machine shops, are characterised by a multitude of bright reflections producing a glitter which gives the factory an unnatural and somewhat befogging appearance.

Direct glare is, of course, a much acknowledged defect, but it may be noticed that a cut-off at 70 deg. does not entirely draw the sting of high brightness sources. Even at angles exceeding 20 deg. from the line of view, such sources are by no means unobtrusive and constantly distract the eye. When

brilliant sources are placed against a background of relatively dark ceiling, the appearance is unnatural and there is a continuous and more or less conscious effort to ignore the effect.

Small shaded local sources are often used on both machines and benches. On some machines there is no other way of lighting deep recesses ; but on open machines such as lathes, the need for a local light probably illustrates the limitations of the general overhead system used, especially as regards the positioning of sources relative to the individual work places. Another cause of fatigue is found where shaded local lights are used without sufficient general lighting. Apart from the psychological effect of a gloomy factory interior, eyestrain results from the contrast between light and shadow, and from the continuous and unnecessary adaptation of the eye to the extremes of brightness.

Another factor on which there is relatively little data is the effect on the eye of the spectral quality of various light sources. There has, of course, been extensive research into the relationship between visual acuity and spectral distribution ; but little is known of the effect on the eye of continued exposure to various distributions when the eye is not relieved by lengthy recuperative periods in natural daylight.

Most artificial light sources have a spectral distribution differing materially from that of natural daylight, and there can be little doubt that the average person finds a north skylight the most restful, whether for physiological or psychological reasons. Colour quality is therefore a factor to be borne in mind in war time when an operative spends most of his waking hours under artificial light of one sort or another.

Where the discrimination of colour is necessary or helpful in the performance of a visual task, imperfect colour rendering will cause strain if perception of detail depends on unnatural methods. Colour rendering has also an important effect upon the appearance of the factory and especially of the operators, and if the lighting engineer is to assist in promoting psychological welfare he must give due weight to this factor.

It will be noted that suitability could be defined to a large extent on the basis of suitable brightness and colour contrast, and suitable brightness levels in the whole field of view—local and general. Essential detail is revealed by suitable contrasts of brightness and colour. Glitter or reflected glare introduces an excessive and meaningless contrast to the local field of view, and perception of detail is achievable —if at all—only by intense effort.

A cheerful and restful appearance is imparted to the factory interior by suitable brightnesses and by natural contrasts of colour and brightness in the general field of view. Glare, reflected glare, and deep shadow introduce fatiguing and depressing contrasts.

Practical Investigation of Suitability in War Time.

The author and his colleagues have for some time been engaged upon an investigation of suitability, and the analysis of wartime conditions has served as a relatively simple basis of enquiry. At first, a visibility meter was used; but this method was almost immediately discontinued and no attempt was made to assess perceptibility of detail apart from personal judgment. War conditions have provided a much more significant and comprehensive criterion in the magnified effect of suitability upon the efficiency and health of the operators. The worker will find some means of performing the visual task even under extremely bad visibility conditions; but the evidence of wasteful methods of perception accumulate both in his work and his condition of health.

If lighting has proved unsuitable after several months of blackout work, this fact is readily determined by observing the results of a change to really high quality lighting. Each case thus provides its own standard of comparison, and those immediately concerned with production can see for themselves the magnitude of the effect. Any visibility meter must neglect the most vital factors in our present problem, and its use pre-supposes a knowledge of the subject which is not available. The scope of the visibility meter may well prove to be limited to the determination of adequacy.

In planning high quality lighting, it was considered that eyestrain and other wasteful effects could be largely eliminated by providing adequate illumination from sources of low brightness and by the exercise of care in eliminating such defects in lighting as those mentioned above.

Throughout, most of this investigation a recently developed light source was used—the 80-watt tubular fluorescent lamp giving about 2,800 lumens from a source 5 ft. long by 1½ in. dia. This lamp has the inherent advantage of a low brightness (about 4 candles per sq. in.) and furnishes light of a colour closely resembling that of natural daylight. The extended shape of this source also assisted materially in solving problems of projecting light on to work

from suitable directions. Thus the lamp can be placed behind the head of the operative without causing noticeable shadow on the work.

With a light source which in itself appeared to eliminate problems of glare and reflected glare, and the colour rendering of which contributed at least to psychological welfare, it was possible to concentrate on the basic problem of providing adequate illumination from suitable directions. Some of the experimental installations used are shown in Figs. 1 to 8.

Some Typical Installations.

The specially equipped Development Workshop shown in Fig. 1 provides a fine example of the way in which lighting controls the whole atmosphere of a shop. The original lighting consisted of low brightness fittings using filament lamps and giving 7 to 8 ft.c. at the working plane. This was supplemented with fully adjustable local lamps, properly shaded and giving 50 to 100 ft.c. on the work. The work consists mostly of high precision machining, fitting and assembly, but varies considerably in character.

At the outbreak of war the skylight was permanently obscured, but the side windows were fitted with removable shutters, and the shop seemed to be well lighted both by day and night. After several months of war work, however, the foreman insisted that better lighting was required, but was himself much surprised at the far-reaching effects of really suitable lighting. A week after switching-on he reported that whereas most of the operators previously were rubbing their eyes and yawning by 5 p.m., and were most reluctant to work overtime, he now found the symptoms had disappeared completely. Within the week the demand for "free time" had subsided and the need of supervision was very greatly reduced. The general debility and fatigue, for which the longer hours of work over several months had been blamed, he now attributed almost entirely to the earlier lighting conditions. It is worth recording also that the foreman had worn glasses regularly for a year before the shop was re-lighted and has not used these at all in the intervening five months.

Roof lights were installed to illuminate the ceiling, and, in the words of one operative, these "definitely take a weight off the head." There is an impression of extremely high visual acuity at illuminations of 40 to 50 ft.c. Polished steel has almost a lack-lustre appearance, somewhat similar to aluminium. This extremely pleasing visibility is mainly due to the absence of sources of high brightness and the elimination of glitter.

In the case of the multiple coil winder shown in Fig. 2 the visual task is naturally exacting and was performed previously in natural daylight. An adequate illumination was provided by local lights,

Fig. 1. With high precision machining, fitting and assembly, this fluorescent installation produces a remarkable improvement in health and workmanship.

Fig. 2. The multiple coil winding machine requires high illumination from low brightness sources.

but it was obviously essential to eliminate glitter. The method shown has proved entirely suitable.

More recently this technique has been applied to the winding of very special coils where the task as a whole is so exacting, and perfection is so important, that the operators are especially selected for their excellent vision. The best human material needs lengthy and most expensive training, and fully trained operators had been lost due to the effects of eyestrain. Any contribution to psychological welfare is here most valuable, and the advantages of simulating daylight quality and of giving the operators themselves a natural appearance cannot be overestimated.

Somewhat similar considerations—both eyestrain and direct psychological strain—apply to the task depicted in Fig. 3. Here a high illumination is necessary for the fine discrimination of detail in specular

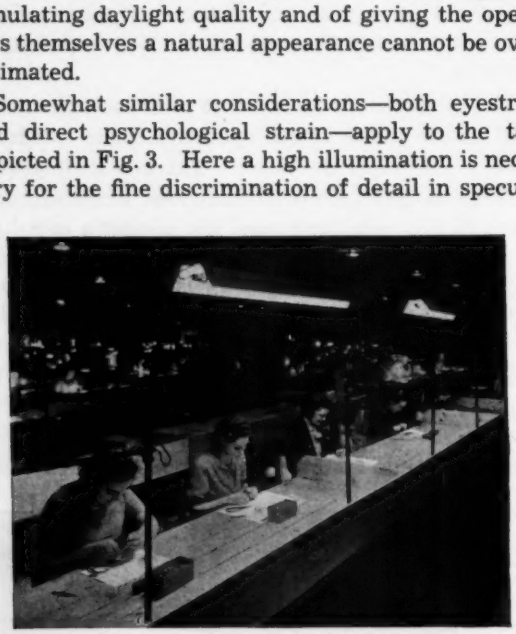

Fig. 3. In the "blacked-out" factory there is often a depressing combination of gloom and glare.

material. In all cases serious dislocation of work has been avoided by attention to lighting quality.

Fig. 4 provides an excellent example of an operative being able to carry on with unsuitable lighting, but with health and work both suffering. His task is the de-burring of gear wheels used in a very sensitive mechanism, and it will be noted that various aids to vision are used. With orthodox lighting this operator suffered from eyestrain and its attendant ills, and was most dissatisfied with the unnatural limitation of his skill. He was entirely content with the new arrangement shown. It is interesting to note that during a recent change of layout the old lighting conditions were here resumed and immediately caused violent headaches. With the restora-

Fig. 4. Daylight quality eliminates severe eyestrain, headaches, and general fatigue.

tion of high quality lighting—which had to be rigged temporarily—the trouble ceased.

This work, and that shown in Fig. 5, is located in a

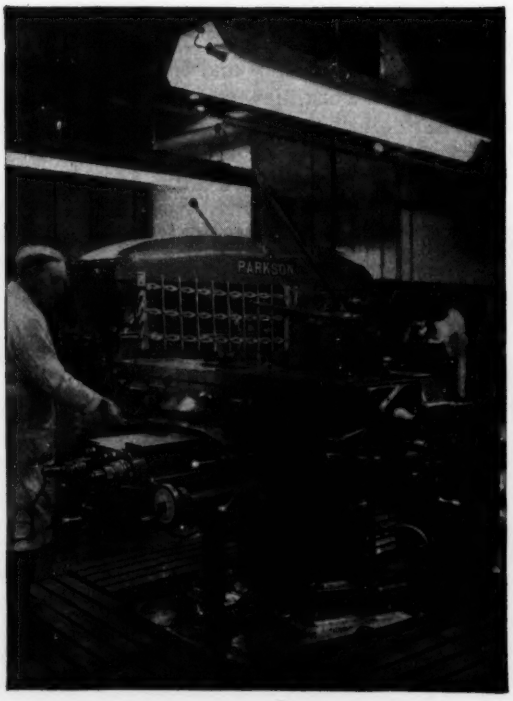

Fig. 5. Excellent visibility of work and of milling machine verniers is obtainable with extended low brightness sources.

new factory built and lighted with present conditions in view. The lighting installation was thought an excellent one when planned in peace time, and the additional cost of generous illumination, improved colour rendering, and some limitation of source brightness was justified on the grounds that the factory would be blacked out in war. Nevertheless, after a few months of blackout working, the entire personnel suffered from eyestrain and general debility. Many operators complained of violent headaches upon going out into daylight. In many cases the polished Vernier scales on micrometers and machines were read only with the greatest difficulty, and this visual task was repeatedly pointed out as a baffling and a most irritating one.

Fig. 6. High quality lighting is as essential on machine tools as at the inspection table.

As in the case of the Development Workshop, high quality lighting gave immediate and greatly appreciated relief, operators being eager to volunteer details. Here, too, an impression of cooler and better ventilated conditions was very marked with daylight quality of light. In the case of one assembly area, the first experiment provided four 80 watt lamps round one table, and before these were switched on one operator complained that the place was hot enough without 320 watts overhead. After a day's use an enquiry was actually made as to whether the lamps in question had any refrigerative effect, as the table concerned was definitely cooler than the rest of the area.

In the case of the lathes shown in Fig. 6, the limiting factor was still the cutting speed of the machines, but spoilage was reduced. Operators were obviously healthier and more buoyant, and volunteered the information that they were not nearly so tired at the end of a shift, while one operator took a much greater interest in his personal appearance.

Fig. 7. The artificial skylight produces a remarkable illusion of natural lighting, due to the daylight colour and the unobtrusively low brightness of tubular fluorescent lamps.

An Inspection Anomaly.

It is a surprising fact that the severity of the visual task at the inspection table is given a ready acknowledgment that is denied to other equally important points in the production line. As a result, the inspector is often provided with high quality lighting which is denied the machinist—hence the obvious anomaly that the inspector could detect errors which the machinist could not avoid and which could not be detected under the machine lighting. The trouble was properly eliminated at the source by giving the machinist suitable lighting. The author has, however, heard of the very opposite solution being suggested—that the high quality lighting should be taken away from the inspectors—a solution which, under present conditions, might have incalculable results!

Artificial Skylight.

The potent psychological effect of daylight quality was first remarked in connection with the artificial skylights shown in Figs. 7 and 8. The effect of complete obscuration of daylight on industrial health and efficiency, and the problem of developing artificial lighting suitable for daytime use, were subjects under investigation by the Industrial Health Research Board.* Figs. 7 and 8 show two of several such installations planned in collaboration with Mr. H. C. Weston.

With these installations the illusion of real daylight was so convincing that the presence of daylight was accepted as natural, and there was no inclination on the part of visitors or operators to examine the source further. By standing at the end of an installation it was possible to compare it with the original lighting simply by turning the head. When casting was in progress in the area shown in Fig. 8 there was a strong impression of cooler conditions and better ventilation. The eyes came to rest naturally at the working plane and were not attracted towards the skylights. In the fettling shop the area lighted by sources of high brightness appeared foggy as compared with the area under skylights, both areas being at the same illumination. This was due to glitter from fettled castings lying about the floor under high brightness sources, and visibility was obviously spoiled by this effect. It was concluded that the unquestioning acceptance of the skylight as natural was due to correct positioning, normal intensities projected from the expected direction, and especially to the unobtrusively low source brightness and the natural colour quality.

Fig. 8. Future factory lighting may consist of luminous ceilings constructed on this principle.

Colour and Brightness of Source.

Throughout these investigations much of the evidence seemed to emphasise the importance of natural colour and of low source brightness. Thus it was found that operatives on day work developed violent headaches upon exposing their eyes to normal daylight at lunch-time and at tea-time, while others were effected during work. Typical cases were cured by the introduction of suitable lighting, and it appeared that colour was an important factor. Again, in a heavy machine shop an overhead system of high brightness sources was supplemented by further high brightness sources. The operatives stated that they "have plenty of light now, but since the powerful lights were installed we are all having to get glasses." From other experience this was attributed primarily to reflected glare from polished metal. Another point mentioned by operatives concerned the involuntary habit of looking at the light source in moments of relaxation from a prolonged visual task. Where the sources were of low brightness this habit caused no embarrassment, but with high brightness sources images were seen for some time, and what was originally a momentary relaxation became a few minutes' interruption of work.

Deductions from Experimental Investigations

The few cases quoted are sufficient to illustrate that war-time lighting conditions are ripe not only for investigation but for effective reform. Whilst in these high-quality installations there were many factors contributing to suitability, the greatest contribution appeared to be the suppression of reflected glare. To attain this condition light sources should have a low brightness in all directions and not only above angles of 70° to the downward vertical.

A factor of almost equally vital importance was found to be the correct positioning of a light source relative to the individual task. As regards adequacy of illumination, it was found that this factor by it-

* See "Daytime Lighting of Blacked-out Factories," by R. Maxted and J. Bertram, "Electrical Times," Vol. 97, No. 2,537, page 481.

self had little meaning in most instances. In the case of work on specular or polished materials the value of any level of illumination depended entirely upon the correct positioning of a low brightness source. The brightening of walls and ceilings by whitewash and adequate illumination was found to be not only of advantage in psychological welfare, but also a real aid to vision. Thus the reflection of these brightened surfaces in specular work lessened the contrast due to reflections of light sources.

In shops having general illumination from large high-brightness sources, it was found that while visibility was greatly improved by a high local illumination from a low brightness source, the effects of reflected glare were not entirely eliminated. Thus local illumination was raised without a corresponding increase in reflected glare, and excessive contrasts on the work were reduced, but it was obvious that the brightness of the overhead units should also be reduced to complete the job. The importance of correct positioning of light sources was repeatedly emphasised, and not least by the use of small local lights in machine shops where quite high illumination is provided by an overhead system.

An Anomaly in "Supplementary" Lighting

In a typical machine shop a total of 216,000 lumens is provided by an overhead system, and lighting essential to the visual task is supplied by low wattage local light totalling 11,000 lumens. These local lights are commonly referred to as "supplementary," probably because of the relatively small lumen output involved; and yet by virtue of suitable positioning these lamps contribute more to the performance of the visual task.

In such a shop it seems clear that the balance between local and general lighting could be effected in a much more favourable manner. The author would suggest a redistribution of the total lumens giving each individual operative a larger share of light from a local unit arranged to suit his individual needs, and using a much smaller percentage of the total lumens in overhead units to provide general brightness of walls, ceilings, and floors. Where the local lighting is not too localised, an excellent appearance can be obtained with the *main* lighting from local units, and the *supplementary* lighting from general units. Thus if each operative were given a properly placed local source of 3,000 lumens, the balance would be 150,000 lumens for local lighting and 77,000 lumens for general lighting. Furthermore, by providing the local lighting from an extended source, the need for constant adjustment of a small local light is eliminated and the efficiency of the operatives can be greatly increased in many instances.

Lighting "Codes."

From these investigations of suitability one is led irresistibly to the conclusion that "adequacy" is an integral part of "suitability" and that an unnatural distinction between the part and the whole should not be encouraged. Such discrimination need not in itself be unnatural or harmful, but lighting practice very commonly makes it so. Thus, "adequacy" is already the subject of a species of code, the I.E.S. "Recommended Values," and while this code has a proper and necessary function, its present lonely status does lend some colour to the popular impression that "adequacy" can be regarded as a separate entity.

With the great diversity in factory layout and in the design of factory buildings to-day, there are great and perhaps insurmountable difficulties in the way of a specific code, and any finality may have to await effective collaboration between architect, factory planner, and lighting engineer.

If this should prove to be the position, the author feels strongly that even so some means should now be devised for showing "adequacy" in a more suitable perspective. This purpose might be achieved in some measure by a purely qualitative code giving general guidance, somewhat on the following lines:—

1. A lighting problem is to be regarded from the viewpoint of the operative and not from that of the casual observer.
2. Ready discrimination of the detail to be perceived shall be provided by adequate illumination from a suitable direction, or by other natural means of perception.
3. Excessive or meaningless brightness contrasts shall be excluded from the work to be viewed —for example, glitter or reflected glare shall be avoided.
4. Glare shall be prevented, either direct or by reflection from the local or from the general fields of view.
5. Provision shall be made for suitable brightnesses of walls, ceilings, and general surroundings.
6. Due weight shall be given to the psychological factors. Design for a natural appearance of the factory interior and of factory life as a whole.

A code of suitability might ultimately specify limits of brightness for the general and for the local field of view, and place an upper limit on the brightness of light sources. Such an achievement cannot be expected in the near future, and suitability must depend for the present almost entirely upon the skill of individual lighting engineers. A very great step forward could, however, be taken now by adding to the I.E.S. code a mandatory clause requiring that source brightnesses should *in no direction* exceed, say, ten candles per square inch. As regards the ultimate value of this figure, the author suggests that it should be such that, immediately after viewing the source, the operative can proceed with an exacting visual task without embarrassment.

Practical Problems.

Although the investigations described in this paper have made use of a new lamp which has certain evident advantages, it must be remembered that supplies of this lamp are at present limited and it is not available for universal use. The next most suitable sources are apparently those fittings using opal glass bowls or visors. Yet here again the present supplies are less than of fittings in which high brightness sources are exposed.

For the immediate present at least, it is therefore desirable to have a basis upon which priority can be assessed. For this purpose work can be divided roughly into four classifications of the field of view:—

1. *Local specular.* — Maintained perception of detail on metal or other specular materials. Precision machining, fitting, and small assemblies requiring high illumination without reflected glare.
2. *General specular.*—General illumination of medium to large assembly work and of machine shops.
3. *Local non-specular.*—Woodworking, etc.
4. *General non-specular.*—For example, assembly of wooden aeroplanes structures in non-specular surroundings.

In the first category it is not possible to realise the desired conditions of perception unless the source brightness is restricted. With sources of brightnesses not exceeding 5 to 10 candles per square inch, excellent visibility may be achieved with adequate illumination and suitable positioning of the source. The two latter requirements almost invariably call for localised lighting, unless the necessary illumination can be provided from artificial or natural north skylights. Localised lighting, however, should not be too localised, and the advantages of an extended overhead local source are usually great as compared with an intensive unit below eye level.

The second category applies to the provision of supplementary general lighting (e.g., 6 ft.c. at working plane) in a shop requiring the localised high illumination of category (1). It also applies to the main overhead lighting required in assembly shops and heavy machine shops (say, 15 to 20 ft.c.). In both cases low brightness units are highly desirable. In the latter case local supplementary lighting for perception of fine detail has often to be provided by adjustable or transportable units, and these should certainly be low brightness units as in the case of category 1.

In the cases of the third and fourth categories the positioning of light sources relative to the work is not so critical, and quite good results can be obtained with high brightness sources arranged in formal pattern overhead, provided that unnatural "tunnel" effects are avoided by the whitening and illuminating of ceilings and walls.

It should be remembered that in all overhead systems the lighting is improved by closer spacing. Thus, smaller units closely spaced are preferable to wide-spaced, high-wattage units. This is obvious when it is realised that such a tendency is towards the ideal of both indirect and natural lighting.

The potentialities of lighting reform are very great, but so are the pitfalls of a relighting programme. It must be realised that there are factories in which the lighting was planned to meet war conditions, but in which the quality of lighting has proved unsuitable for the maintenance of efficiency and of output under war conditions. The danger lies not merely in failing to replace unsuitable "modern" installations, but in having these quoted as examples for the relighting of other factories on similar work. In the planning of such installations, war-time requirements could only be *predicted*, since immediate experience was not available. The lighting engineer should therefore examine for himself the suitability of certain installations under war conditions and should base his recommendations upon his own judgment and not upon the opinions of others who may well have been casual observers.

Economics and Perspective.

It is inevitable that these two words should be linked in regard to war-time industrial lighting, for

undoubtedly a true perspective of the subject is concealed in a mist of hazy economics. Thus, while industry requires as never before the best contribution to industrial health and efficiency of which he is capable, the lighting engineer is still shackled by the traditions of a peace-time economy—an economy that is unlikely to return even after the war.

That such an anachronism should now be found is not surprising when it is realised how little anticipation there was of war-time lighting requirements. It will surprise many people now to be reminded that before the war the possibility of using A.R.P. fittings *inside* the factory was contemplated! It may be with equal surprise that in years to come we recall how we expected our peace-time compromise in lighting suitability to endure under war conditions.

The gaining of a true perspective of the present position depends simply upon clearing the obscurity of the influence of lighting on factory economics. Industrial managements have already shown considerable imagination in promoting human efficiency by attention to purely psychological factors (such as music in industry and the more physiological mid-morning and mid-afternoon breaks and refreshment). It is realised to-day that the effective combining of man and machine is a very complex matter, and in years to come our present best attempts at applying light for this purpose may well be regarded as crude and unimaginative—just as the modern industrialist must view nineteenth-century efforts at industrial planning.

But while current experience is providing a surer basis for future practice, it is also producing hard facts, calling for immediate and effective improvisation in regard to both suitable supplies and effective methods. Surely one of the youngest of engineering sciences can be expected to show a resource and an imagination in keeping with the spirit and needs of the times.

The author is indebted to Mr. H. Warren, Director of Research, for permission to publish the results of investigations made in the B.T.H. research laboratories. He wishes to express his appreciation of many profitable discussions with Mr. J. S. Dow and Mr. H. C. Weston; with many colleagues, particularly Mr. Bertram and Mr. MacDiarmid; with Mr. Phillips and Mr. Cator; and with the superintendents, foremen, and operatives of a number of factories and workshops.

Annual General Meeting and Luncheon

The arrangements on May 13, when the annual general meeting, followed by a sessional meeting and preceded by an informal luncheon at St. Ermin's Hotel, had been fixed, passed off quite satisfactorily. A formal record of the proceedings at the meeting will appear in a coming issue of "The Transactions," together with the report of the council and the accounts of the society for the past year.

Prior to the luncheon a conference of representatives of Local Centres was arranged at St. Ermin's Hotel. Numerous points of common interest were considered and full discussion was deferred until a forthcoming all-day conference, provisionally arranged to take place in Leeds on July 2.

The representatives of Local Centres, who were subsequently present as guests of the society at the luncheon, were as follows:—

North Midland Centre.—Mr. J. W. Howell (chairman), Mr. W. F. Pogson (hon. secretary), and Mr. H. W. Harris (hon. treasurer).

Midland Centre.—Dr. W. M. Hampton (chairman), Mr. C. J. Allderidge (hon. secretary), Mr. Howard Long, Mr. R. Maxted, and Mr. W. J. P. Watson.

North-Western Centre.—Mr. A. H. Owen (hon. secretary).

Nottingham Sub-Centre.—Mr. C. S. Caunt (hon. secretary), Mr. M. Wadeson.

Glasgow Centre.—Mr. E. J. Stewart (chairman), Mr. M. W. Hime (hon. secretary).

At the luncheon the toast of "The Illuminating Engineering Society" was proposed by Mr. Howard Robertson. The President responded.

The afternoon meetings took place in the lecture theatre of the Institution of Mechanical Engineers (Storey's Gate, Westminster). The customary formal resolutions were passed adopting the report and accounts for the past year and re-electing auditors, after which Col. Kenelm Edgcumbe presented the new By-Laws in their final form. These were approved, subject to formal ratification at a forthcoming special meeting.

In the course of the meeting it was announced that, as a result of a postal ballot, the following had been elected members of Council: Mr. T. Catten, Dr. W. M. Hampton, Mr. J. W. Howell, Mr. W. F. Pogson, Mr. J. S. Preston, Mr. E. B. Sawyer, Mr. P. Crawford Sugg, Mr. H. C. Weston, and Dr. W. D. Wright.

At the sessional meeting following, Mr. R. O. Ackerley delivered an address reviewing Lighting Problems Involved in Post-war Reconstruction. Following some remarks by members of the society and by architects and others present as guests of the society, a resolution requesting the Council to initiate forthwith the study of these reconstruction proposals was passed unanimously.

Recent Meetings in Birmingham

The Midland Centre, which was unable to complete part of its original programme owing to circumstances beyond its control, decided to carry on with meetings in the early summer, when the full advantages of longer hours of daylight could be secured.

At a meeting held in the Municipal Technical College, Birmingham, on April 25, an address on War-Time Photometry was given by the President (Professor J. T. MacGregor-Morris), Dr. W. M. Hampton presiding. The address was devoted largely to problems involved in making measurements of illumination at very low illuminations. Examples of special photo-meters devised to meet war-time requirements were shown, and some experiments on visibility in very weak light recently shown in London were repeated. There was a keen discussion and a vote of thanks to the President terminated the proceedings.

At a subsequent meeting, also held in Birmingham, on May 23, Mr. E. W. Murray gave an address on A.R.P. Lighting Problems. After dealing with the effect of the black-out on industrial lighting and referring to the "Factories (Standards of Lighting) Regulations," Mr. Murray passed on to the review of conditions affecting visibility out of doors. He discussed and illustrated the design of light-locks and A.R.P. fittings, the lighting of obstructions, the problem of war-time street lighting, and the use of illuminated signs of low brightness, dwelling on such points as the effect of glare and the part played by contrast under present conditions.

APPLICATIONS FOR MEMBERSHIP.

Elections Pending.

The names of the following applicants for membership were presented for the first time at the meeting held on May 13, 1941:—

CORPORATE MEMBERS:—

Aldington, J. N. .....Siemens Electric Lamps and Supplies, Ltd., Dock Road, PRESTON.

Harkness, A. R. .....1, Forest Crescent, Ashtead, SURREY.

Harrison, P. G. .....15, Castle Grove Avenue, LEEDS, 6.

Heuthwaite, A. H. ...British Thomson-Houston Co., Ltd., 46, Wellington Street, LEEDS.

Jewiss, G. A. P. .....71, New Holifast Road, Erdington, BIRMINGHAM, 24.

Lawrence, J. .....The General Electric Co., Ltd., Waterloo Street, GLASGOW.

Maistre, J. P. D. .....49, Shaftesbury Avenue, Kenton, Harrow, MIDDX.

McCullough, R. de B. Wood Farm, Daventry, NORTHANTS.

Partridge, C. F. .....Central Technical College, Suffolk Street, BIRMINGHAM.

Retting, L. C. .....16, All Saints Road, BRISTOL, 8.

Rigby, H. .....1, Earlswood Avenue, Roundhay, LEEDS.

Tremain, H. J. .....16, Canfield Road, Woodford Bridge, ESSEX.

Winter, A. H. .....5, Marsh Lane, Solihull, BIRMINGHAM.

COUNTRY MEMBER:—

Buxton, W. H. .....Elmfield, 75, Powell Street, DERBY.

Elections Completed.

The list of applicants for membership, whose names had been presented at the previous meeting on April 8 (Trans. Illum. Eng. Soc., Vol. VI., No. 3, May, 1941, p. 48), was again presented, and these gentlemen were formally declared members of the Society.

TRANSFERENCES FROM COUNTRY MEMBERSHIP TO CORPORATE MEMBERSHIP:—

Davey, J. G. .....11, Acacia Road, Leamington Spa, WARWICKSHIRE.

Dain, F. P. .....Corporation Electricity Showroom, Corporation Street, COVENTRY.

Lappin, T. M. .....Public Lighting Department, 1, Lochee Road, DUNDEE.

Pashler, A. P. .....9, Leopold Avenue, Handsworth Road, BIRMINGHAM, 20.

Roper, F. H. .....47, Highfield Lane, Quinton, BIRMINGHAM, 32.

Reynolds, E. A. .....57, Colmore Row, BIRMINGHAM.

Watson, W. J. P. .....91, Brandwood Road, King's Heath, BIRMINGHAM, 14.

I.E.S. FELLOWSHIP.

Applications for Fellowship on behalf of the following have been accepted by the Council:—

Hime, M. W. .....E.L.M.A. Lighting Service Bureau of Scotland, 29, St. Vincent Place, GLASGOW, C.1.

Sawyer, E. B. .....E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, LONDON, W.C.2.

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PROCEEDINGS AT THE ANNUAL GENERAL MEETING

(Held on Tuesday, May 13, 1941)

The Annual General Meeting of the Illuminating Engineering Society, followed by an ordinary sessional meeting, was held in the Lecture Theatre of the Institution of Mechanical Engineers (Storey's Gate, Westminster, S.W.1) on Tuesday, May 13, 1941. The chair was taken by THE PRESIDENT (Professor J. T. MacGregor-Morris) at 3 p.m.

THE HONORARY SECRETARY having read the notice convening the meeting, the minutes of the last annual general meeting, which had been published, were taken as read and confirmed. The Hon. Secretary then briefly presented the report and accounts for the past year, dwelling on several encouraging features, such as the record of meetings held, the maintenance of membership and income, and the carrying through of the scheme of Fellowship.

Attention was drawn to the fact that on this occasion a postal ballot for Members of Council had been carried out under the supervision of the Council. In the course of the proceedings the report of the scrutineers was presented and it was announced that the following had been elected: Mr. T. CATTEN, Dr. W. M. HAMPTON, Mr. J. W. HOWELL, Mr. W. F. POGSON, Mr. J. S. PRESTON, Mr. E. B. SAWYER, Mr. P. CRAWFORD SUGG, Mr. H. C. WESTON, and Dr. W. D. WRIGHT.

A resolution— "That the Report of the Council for the Session 1940-1941 and the Accounts of the Illuminating Engineering Society for the period from January 1, 1940, to December 31, 1940, be hereby adopted, and a Vote of Thanks be extended to the President, Council, and Officers for their efforts on behalf of the Society during the past Session"—was proposed by Mr. G. HERBERT and seconded by Mr. H. W. HARRIS.

In moving the resolution, Mr. G. HERBERT, as a member of many years' standing, recalled the numerous meetings which he had attended and congratulated the President, Council, Officers, and staff on maintaining activities so well under what must have been very trying conditions. Mr. H. W. HARRIS, in seconding, expressed the recognition on the part of members in provincial cities of the able manner in which the affairs of the Society had been carried on. The arrangements for meetings and the state of the accounts reflected great credit on those concerned, and the President, who had performed his duties with dignity and efficiency, deserved a special tribute.

This resolution having been carried with acclamation, the President briefly responded, adding his personal appreciation of the efforts of the Council and the staff.

A resolution—"That this meeting records appreciation of the services of Messrs. Robert J. Ward and Co. as Auditors of the Society, and approves their re-election for the next Session"—moved by MR. L. G. APPLEBEE and seconded by MR. D. W. DURRANT, was declared carried unanimously.

Lt.-Col. KENELM EDGCUMBE then presented the Revised By-Laws which had been previously circulated to all members. He reminded those present that the substance of these By-laws had been approved by members at a special meeting held on December 5, 1939. It has subsequently been found necessary to have them overhauled by a solicitor and put into legal form. As a result some changes, chiefly in the rearrangement of certain clauses, had been made. The general effect was to make the By-laws shorter and more concise. There was practically no departure on matters of principle, but the speaker drew attention to one or two alterations in procedure, notably in regard to the election of members, which would be effected more simply and expeditiously under the new conditions.

Following this explanation by LT.-COL KENELM EDGCUMBE, it was moved by MR. PERCY GOOD and seconded by MR. A. CUNNINGTON "That this meeting accepts the Revised By-Laws and asks the Council to put them before an Extraordinary Meeting at the earliest convenient date." This resolution was declared carried unanimously.

(Mr. R. O. Ackerley's address on Lighting Problems in Post-War Reconstruction, and the comments made thereon at the sessional meeting following the annual general meeting, will appear in a subsequent issue of THE TRANSACTIONS).

Extraordinary Meeting on June 24, 1941

Formal Acceptance of Revised By-Laws

At an Extraordinary Meeting held at the E.L.M.A. Lighting Service Bureau on Tuesday, June 24, the Revised By-Laws presented were formally accepted.

After the Hon. Secretary had read the notice convening the meeting the following resolution was put by Lt.-Col. Kenelm Edgcumbe, seconded by Mr. Percy Good, and declared carried unanimously: "That the Revised By-Laws of the Illuminating Engineering Society, as presented at the Annual General Meeting on May 13, 1941, be hereby approved and adopted."

These By-Laws are published in the present issue (pp. 68-70).

This concluded the business before the Extraordinary Meeting. A sessional meeting was then held at which the names of applicants for membership, announced at the previous meeting on May 15, were again presented, and these gentlemen were formally declared members of the Society.*

A short address was then delivered by Mr. E. B. Sawyer explaining, with demonstrations, the objects of the Exhibition of Industrial Lighting at the Bureau. A vote of thanks to Mr. Sawyer for his address and to the Bureau for their hospitality terminated the proceedings, after which members adjourned to inspect the exhibition.

* See Trans. Illum. Eng. Soc. (London), Vol. VI., No. 4, June, 1941, p. 60.

REPORT OF THE COUNCIL FOR THE SESSION
OCTOBER, 1940, TO MAY, 1941

(Presented at the Annual General Meeting, held on Tuesday, May 13, 1941.)

During the past session the Society has again been called upon to meet exceptional conditions which have caused some interference with programmes in certain localities. Nevertheless, it has been found possible to hold regular meetings, both in London and in provincial cities, and to maintain the activities of the Society with a considerable degree of success.

Upwards of eighty members of the Society are known to be serving with the Forces, and many others have been occupied in special forms of national service, such as the researches on A.R.P. lighting mentioned in the Report for the previous session, which are still being continued.

Election of Officers and Council for Next Session.

In accordance with the procedure outlined in the Articles and By-Laws of the Society, the nominations made by the Council to fill vacancies have been printed in THE TRANSACTIONS of the Society, and corporate members have thus been afforded an opportunity of making additional nominations. No new nominations having been received in regard to officers of the Society the proposals of the Council stand.

Accordingly, Mr. W. J. Jones will become president, Mr. R. O. Ackerley, Dr. H. Buckley, and Mr. E. J. Stewart will continue in office as vice-presidents. Mr. J. S. Dow will continue to act as honorary secretary, and Mr. E. W. Murray will continue to act as honorary treasurer.

In addition to the nominations put forward by the Council, members of the North Midland Centre have submitted independent nominations on behalf of Mr. J. W. Howell, Mr. W. F. Pogson, and Mr. R. O. Seville for Council Membership. Accordingly, the following ten nominations are now offered for the existing nine vacancies: Mr. T. Catten, Dr. W. M. Hampton, Mr. J. W. Howell, Mr. W. F. Pogson, Mr. J. S. Preston, Mr. E. B. Sawyer, Mr. R. O. Seville, Mr. P. Crawford Sugg, Mr. H. C. Weston, and Dr. W. D. Wright.

The Council is arranging for a postal ballot, the result of which will be announced at the Annual General Meeting.

Appointment of Committees.

In view of the prevailing conditions and the exceptional demands upon the time of many members, the procedure adopted during the past session of forming a special *Executive Committee* was again followed. The Committee, which was formed by the enlargement of the General Purposes Committee, was constituted as follows:—

Professor J. T. MacGregor-Morris (President), Mr. R. O. Ackerley, Dr. H. Buckley, Mr. A. Cunnington, Mr. J. S. Dow (hon. secretary), Dr. S. English, Mr. Percy Good, Mr. W. J. Jones, Mr. E. W. Murray (hon. treasurer), Mr. F. C. Smith, and Mr. E. Stroud.

This committee has served its purpose in dealing quickly with all essential questions and reporting at suitable intervals to the Council, which has continued to meet, but at somewhat less frequent intervals than in normal circumstances.

The only other operating Standing Committee, the *Papers Committee*, was constituted as follows:—

Dr. H. Buckley (Chairman), Mr. T. Catten, Mr. C. E. Greenslade, Mr. R. Maxted, Mr. F. C. Smith, and Mr. J. M. Waldram.

The committee has initiated an interesting series of events for the past session and is now engaged in preparing the programme for 1941-42.

Sessional Meetings in London.

Regularly monthly meetings have been held in London, and good audiences have been obtained notwithstanding the change of the time of meetings to 2.30 p.m. The opening meeting, on October 8, was devoted to the Presidential Address, which on this occasion took the form of a demonstration lecture on the Carbon Arc as a Standard of Light. The Society was privileged to hold this gathering in the historic lecture theatre of the Royal Institution.

The following meeting on October 22, 1940, was devoted to a paper on Industrial Lighting in War Time by Mr. H. C. Weston. Subsequent contributions dealt mainly with A.R.P. Lighting Problems and with phenomena of vision associated with the very weak illuminations experienced in our streets.

A joint contribution illustrating the part played by contrast in illuminating engineering, prepared by Mr. J. M. Waldram, Dr. R. G. Hopkinson, and Mr. W. R. Stevens was presented on December 10, 1940.

A paper on the Fundamental Principles of Vision in Very Weak Light was read by Dr. W. D. Wright on January 14, when the Report on War Time Street Lighting and Aids to Movements in the Streets, prepared for the Joint Committee formed by the Ministry of Home Security in conjunction with the Society, was also presented for discussion.

Other contributions dealt with the Recognition of Coloured Light Signals (Mr. J. G. Holmes) Motor Car Headlights Restrictions (Mr. J. F. Stanley), Fittings for Providing Low Values of Illumination (Mr. R. Maxted), A.R.P. Signs (Mr. J. Bertram), the Measurement and Gauging of Low Values of Illumination and Brightness (Dr. J. W. T. Walsh). and Visibility by White and Coloured Light (Mr. J. S. Dow).

Many of these contributions were accompanied by interesting demonstrations and experiments.

On the occasion of the annual General Meeting on May 13 it is again proposed to arrange an informal luncheon. The annual General Meeting will be held early in the afternoon. Following the transaction of formal business an address, reviewing lighting problems involved in connection with post-war reconstruction, is to be delivered by Mr. R. O. Ackerley.

The Council desire to record once more their appreciation of the hospitality of the E.L.M.A. Lighting

Service Bureau whose exceptional facilities enabled many interesting experiments and demonstrations, illustrating the above topics, to be arranged.

The Leon Gaster Memorial Fund.

A statement of income and expenditure of this fund, which is now in its tenth year of operation, is appended. The ninth award of the Leon Gaster Premium of ten guineas was made during the past session to Mr. C. Dunbar, for his contribution entitled "Visual Efficiency in Coloured Light," which appeared in THE TRANSACTIONS of the Society for October, 1939.

North Midland Area Local Centre.

The Committee of this Local Centre, which two years ago requested and received formal recognition, is constituted as follows:

Chairman: Mr. J. W. Howell.

Vice-Chairman: Dr. E. C. Walton.

Hon. Secretary: Mr. W. F. Pogson.

Committee: Mr. E. J. Arnold, Mr. L. Bridgewood, Mr. F. Firth, Mr. J. D. Green, Mr. W. Hetherington, Mr. W. I. Ineson, Mr. A. Kelso, Mr. H. Peters, and Mr. R. O. Seville.

Mr. T. C. Holdsworth has been succeeded as honorary secretary by Mr. W. F. Pogson.

The Centre has organised a number of meetings. Papers presented included "Industrial Lighting in War Time," by Mr. R. Maxted, and "Light and the Eye," by Dr. Wellwood Ferguson. At the first of these meetings local inspectors of factories were present and on the latter occasion local consulting ophthalmic surgeons and the Medical Officer of the Leeds Education Committee attended.

An informal luncheon was arranged in Leeds on November 11, 1940, at which over 100 members and guests were present, including leading representatives of other local centres.

The membership of the Centre has been fully maintained. The number of Fellows and Corporate Members exceeds 100, and about twenty new members have been enrolled. Under present conditions it has not been found possible to proceed with the development of the sub-centre in Hull. Unfortunately, the whole of the records of the Sheffield Sub-Centre suffered destruction and activities were suspended for a time. It is hoped, however, that progress in both areas will be resumed in the future.

Other Local Centres.

It is a matter for congratulation that the various Local Centres have been able to maintain so well their programmes of meetings. Two changes in secretaryship may be noted. Mr. C. J. Allderidge has now undertaken the duties of honorary secretary for the Midland Area, under the chairmanship of Dr. W. M. Hampton; and Mr. Alan H. Owen is now honorary secretary of the North-Western Area, where Mr. J. Taylor presides.

Two main features of the programmes may be noted, the repetition at various Centres of certain papers of common interest (including some originally presented in London), and the occasional organisation of "problems" evenings, to which useful contributions by local members were made.

The Presidential Address was repeated, with demonstrations, at an exceptionally successful meeting of the Glasgow Local Centre, held in Glasgow on Dec. 18, 1940. The paper on the Photometric Properties of Some Luminescent Materials, by W. E. Harper, Miss Margaret B. Robinson, and J. N. Bowtell, originally read in London in April, 1940, has been repeated on two occasions: before the North-Western Local Centre on November 25, and before the Nottingham Sub-Centre on November 29, 1940. Dr. J. Wellwood Ferguson, whose address to the North Midland Centre on Light and Vision has been noted above, gave a similar talk earlier to the North-Western Centre. Mr. R. Maxted's paper on Industrial Lighting in War Time was delivered in Leeds, Birmingham, Nottingham, Manchester, and Glasgow.

It is encouraging to record that in spite of the very difficult conditions that have prevailed in certain cities, about twenty meetings have taken place before Local Centres. The thanks of the Society are due particularly to the President and other members who have on occasion travelled long distances in order to deliver addresses.

The method adopted in London of holding meetings early in the afternoon was not considered practicable in most other cities, and meetings were in general commenced early in the evening. The Midlands Local Centre, however, part of whose programme had necessarily to be postponed, has adopted the enterprising experiment of transferring these dates to the summer months, the first item being an address by the President on April 25.

It will be recalled that in the Report for 1939-1940 a reference was made to the difficulties then experienced by the North Western Centre, where the holding of meetings had been practically discontinued. Subsequently the President (Mr. F. C. Smith) and the Hon. Secretary attended a special meeting held in Manchester at which the position was fully discussed, and new officers and committee were elected. It is satisfactory to record that activities have been fully restored. Regular meetings have been resumed, and additions to the membership have been secured.

The sub-centre in Nottingham, the formation of which was announced last year, has held five meetings and has again had a successful session. Professor H. Cotton, who delivered an address at the opening meeting on the Nature of Light, acted as Chairman, Mr. C. S. Caunt continues as hon. secretary.

The Council has carried into effect the steps summarised in the last Report, with a view to maintaining contact with local centres. Although present conditions have naturally rendered difficult the frequent attendance of representatives of other cities at Council meetings, the distribution of records of proceedings has helped to keep them informed of developments. The conference of representatives of local centres, initiated two years ago, will again be held on May 13, but in deference to the wishes of

those coming from a distance will take place during the morning.

It is recorded with sympathetic regret that the sub-centre in Coventry, after making what was in the circumstances a courageous effort to initiate activities in September last, found it inevitable to discontinue meetings. Following the inaugural meeting a second meeting was held on October 14 at which an address was given by Mr. C. J. Pritchard on Illumination and its Effect on Electricity Supply. No further meetings have since been found possible. At the date of the cessation of activities over thirty members had been secured. Mr. F. C. Dain had been elected chairman and Mr. J. W. Dainty honorary secretary.

For some little time a desire for a Local Centre in the south-west area has been expressed. Preliminary efforts in this direction have been made by one of the few members of the Society in that area, Mr. S. G. Turner. Additions to the local membership are now being made, but it is felt best to acquire a larger nucleus before an effort to initiate a local centre is made.

Publications.

It has fortunately been found possible to continue the issue of THE TRANSACTIONS in its present form, though the changed procedure in regard to meetings, necessitated by war conditions, and the longer period necessary for the preparation of papers and contributions has occasioned some delay in issue. Restrictions in the supply of paper have so far not unduly affected publication, but from now onwards the position will doubtless become more difficult and some measures of economy may prove necessary. The regular issue of *Light and Lighting* has proved helpful as an alternative means of disseminating information to members. Every effort will be made to continue both publications, which are of special value in the present circumstances.

Membership.

Since the commencement of the new session about 90 new members of all classes have been added to the list, as compared with an addition of 100 in the corresponding period last year. This figure appears encouraging, especially in view of the fact that 70 per cent. of applications came from those who desired to become Corporate Members, though greater efforts in some areas might well result in still further additions. Apart from the list of members known to be serving with the Forces, there have again been a number of resignations, and, as might be expected in the present circumstances, the number of cases of members whose addresses cannot be traced, shows a tendency to increase. Nevertheless, taking all such factors into consideration, it appears that the estimated total membership mentioned in the last Report (950) is at least being maintained. Of this number approximately two-thirds are now Fellows and Corporate Members, about half of whom are resident in or near London and about one-sixth are attached to the North Midland Local Centre. There is every indication that the interest of members as a whole in the Society has in no way diminished, and that, on the termination of hostilities, a considerable increase in membership might well be expected.

The Council has again to record with regret the loss of several members of the Society of long standing. Amongst these are included Mr. C. H. Merz, the eminent consulting engineer; Mr. C. Valon Bennett, general manager and secretary of the Rochester, Chatham, and Gillingham Gas Company; and Mr. E. L. Oughton, district engineer and research engineer to the South Suburban Gas Company, who was at one time a Member of Council.

Honorary Membership.

As already announced in THE TRANSACTIONS*, the Council has elected Mr. Alexander Pelham Trotter an Honorary Member of the Society. Members will doubtless endorse with acclamation this recognition of Mr. Trotter's past services to the Society and his long and honourable association with illuminating engineering.

Revision of By-Laws.

As mentioned in the Report for 1939-40 the Council felt it expedient to obtain legal advice in regard to the new by-laws, in which the conditions of fellowship were outlined. This examination has now been completed. The clauses relating to fellowship have been approved, and the opportunity has been taken to correct certain anomalies and to arrange the matter in a more compact and simplified form.

It is hoped to present this final draft for the approval of members at the forthcoming Annual General Meeting. In the main no changes in principle are involved, but a more expeditious method of completing the formalities of election is proposed.

Fellowship.

It was announced at the last Annual General Meeting the Board of Fellows had been constituted. During the past session many applications for Fellowship have been received and considered. As a result, eighty-one Fellows have been elected to date.

The possibililty of gaining this distinction has served as an inducement to members qualified for Country Membership to transfer into the class of Corporate Membership, and it is noteworthy that the proportion of candidates applying for this grade of membership is progressively increasing.

The Council takes this opportunity of thanking those members who have served on the Board for the careful and conscientious manner in which they have discharged their difficult duties.

Examinations in Illuminating Engineering.

It has fortunately been found possible to continue the holding of the examinations in illuminating engineering, initiated by the City and Guilds Institute, for the first time in 1939. Although the number of candidates was naturally somewhat less than in the

*Feb., 1941, p. 34.

previous year, not only the intermediate but also the final grade examination was held. Five candidates entered for each examination, and in view of the high standard attained by the leading candidates medals were awarded, the bronze medal to Mr. H. R. Redmill, and the silver medal to Mr. Norman Schofield, a member of the Society who passed in both Sections A and B of the Final examination. It is of interest to record that the 1940 Intermediate examination was successfully taken by a candidate at Melbourne, Australia.

Financial Position.

The accounts for the past year, which are attached, reveal an encouraging position. The increase in subscriptions recorded for 1939 was due mainly to certain exceptional factors, such as the transference from Country Membership to Corporate Membership of the majority of members attached to the North Midlands Area Local Centre. It is noteworthy, therefore, that the income from subscriptions again shows an increase (of approximately £55), notwithstanding the facts that some areas have been adversely affected by war conditions, and that it has been found impracticable to develop certain sub-centres in the manner anticipated.

Included in the receipts is a donation of fifty guineas from the London County Council, a much appreciated recognition of the value of the researches on the lighting of cinema auditoriums, conducted for the London County Council in response to a request conveyed by that body in 1936.

Increase in expenditure is due partly to the higher allocation made to Local Centres, an indication of greater activity on their part than in the previous year, and to the higher grant made to the honorary secretary for administration expenses in view of the present exceptional conditions. Out of the excess of income over expenditure (£283 8s.), £250 has been devoted to the purchase of National Defence Bonds, bringing the total held to £500.

Of the other funds there is little new to record. The temporary overdrafts on the accounts of the National Illumination Committee Fund and the International Illumination Congress Fund have now been extinguished by the receipt of interest. In the case of the Leon Gaster Memorial Fund a transfer of £5 was made from the General Fund in order to supplement the interest received and enable the premium to be met without diminishing the capital.

One feature affecting all the funds may be noted, the increase in the quotation for Registered War Stock, as compared with that recorded in the last balance-sheet, which in most cases brings the value above the purchase price.

Researches on A.R.P. Lighting.

Work on problems associated with A.R.P. Lighting has been proceeding steadily, under the ægis of the Joint Committee formed by the Ministry of Home Security and the Society. The co-operation of the British Standards Institution, whose Joint Director, Mr. Percy Good, continues to preside over the Joint Committee, has again proved of very great value. Much of the work has taken the form of developments in methods previously initiated. Modifications and improvements in a number of British Standard Specifications have been made, notably in those dealing with War Time Street Lighting, Fittings for Furnishing Low Values of Illumination, Fluorescent and Phosphorescent Paint for A.R.P. Purposes, and Gauges for the Testing of Low Illuminations.

Amongst new specifications issued may be mentioned those dealing with Headlamp Masks for Motor Vehicles and Tramcars, the Ventilation of Buildings under Conditions of Black-Out, and a Portable Standard of Brightness. New methods have been found necessary in connection with the photometry of coloured light of low intensity, for which a new unit of " effective brightness " has been introduced.

Many thousands of special fittings complying with the specification for War Time Street Lighting are now in use throughout the country. Their adoption has proved of great benefit during black-out conditions throughout the winter, but hopes have been expressed that some further alleviation of black-out conditions may ultimately be found possible. In this connection great interest has been taken in the Report on " War Time Street Lighting and Aids to Movements in Streets," issued by the Society in December last, in which methods of getting the best effect from the present order of illumination are reviewed, and some possible improvements indicated.

The study of the effects of war time street lighting and of the visibility of illuminated outdoor areas in general has been the subject of further intensive study. A complete record of all researches conducted by the Society to date has been prepared for the Authorities, and it is hoped that much of this information may be made available to members after the termination of the war.

Relations with Other Bodies.

Members of the Society have continued to serve on the Departmental Committee on Lighting in Factories and Workshops, and on committees operating under the National Illumination Committee, the British Standards Institution, and the Department of Scientific and Industrial Research.

New history was made by the issue of the Fifth Report of the Departmental Committee on Lighting in Factories in August, 1940, and by the subsequent incorporation of its main recommendations in the Factories (Standards of Lighting) Regulations, which came into force in February, 1941.

The raising of lighting in factories engaged on work of national importance to the standard specified in these Regulations has called for strenuous efforts by all sections of the lighting industry. In order to afford the necessary national industrial lighting service, a joint lighting committee, under the chairmanship of Sir Duncan Wilson, has been set up by the electrical industry, and similar measures have been taken by the gas industry to deal with gas-lighted factories.

An event of interest has been the formation by the

Physical Society, on February 12, of the "Colour Group," which is concerned with the study of colour and, in particular, standardisation, specification, and nomenclature, in connection therewith. The chairman is Dr. W. D. Wright, and other members of the Illuminating Engineering Society, which is one of the affiliated bodies, are taking an active part in its activities.

Programme for the Next Session.

The tendency previously noted for the services of members to be absorbed in special researches on problems arising through the war still continues. Nevertheless, it is hoped to maintain the normal activities of the society and to prepare a useful programme of meetings for the forthcoming session. Offers of help in this connection will be welcome, and papers and suggestions in regard to meetings are invited. Wherever possible authors of papers are asked to prepare manuscripts in good time before the opening of the session in October next, so that ample time may be available to allot dates, and to take any measures necessary to ensure informative and successful meetings. Attention has been drawn to the numerous lighting problems that will demand solution during the post-war reconstruction period. It is hoped that some of these may be reviewed during the coming session.

The Council desire to take this opportunity of thanking the many members who have assisted in the arduous work of committees, have undertaken secretarial duties, or have otherwise aided in maintaining the activities of the Society during a somewhat difficult period

J. T. MacGregor-Morris (*President*).
John S. Dow (*Hon. Secretary*).

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1940.

Dr. EXPENDITURE.	£ s. d.	£ s. d.
To Administration Expenses:—		
Rent and Clerical Assistance ...	350 0 0	
Printing, Stationery, etc.	197 4 3	
Duplicating	35 7 5	
Postage and Office Expenses... ...	115 3 10	
General Meetings in London:— £ s. d.		
Hire of Halls 20 2 0		
Reporting and Lantern Operating 23 12 6		
Refreshments 12 1 9		
	55 16 3	
Special Meeting (A.R.P. Lighting):—		
Cost of Hall	12 12 0	
Sectional Meetings in London	— — —	
Annual Luncheon (in lieu of dinner)		
Payments 27 18 3		
Less Receipts ... 26 3 9		
	1 14 6	
Local Centres:—		
N. Midland Centre—		
Provision of £ s. d.		
Subscriptions 74 3 6		
Less unexpended... 7 3 6		
67 0 0		
Remittances to other Centres for Expenses of Meetings... ... 82 15 0		
	149 15 0	
,, Bank Charges	16 3	
,, Audit Fee	10 10 0	
		928 19 6
,, Cost of Printing Transactions, Reprints, Blocks, etc.	308 0 8	
Less Sales of Reprints	78 18 4	
		229 2 4
,, Illuminating Engineering Publishing Co., Ltd.:—		
Allocation and Share of Subscriptions		436 6 0
,, National Illumination Committee		32 0 0
,, British Standards Institution		10 10 0
,, Transfer to Leon Gaster Memorial Fund		5 0 0
,, Premium on Deferred Annuity to Staff		38 15 3
,, Honorarium to Staff		16 0 0
,, Excess of Income over Expenditure		283 8 0
		£1,980 1 1

INCOME. *Cr.*	£ s. d.
By Subscriptions	... 1,833 8 0
,, Special Donation from the L.C.C.	52 10 0
,, Subscriptions Outstanding (Estimated)	20 0 0
,, Interest on War Stock	62 4 1
,, Bank Interest	2 11 4
,, Sundries, Subscriptions to Transactions, etc. ...	9 7 8
,, Annual Dinner—	
Receipts	— — —
Less Payments	— — —
	£1,980 1 1

BALANCE SHEET, 31st DECEMBER, 1940.

LIABILITIES.	£ s. d.	£ s. d.
Creditors		71 9 4
Subscriptions paid in advance		— — —
Capital Account:—		
Balance per last Account	2,138 16 7	
Add Excess of Income over Expenditure for the year	283 8 0	
		2,422 4 7
		£2,493 13 11

ASSETS.	£ s. d.
Cash at Bank	396 6 8
Cash in hand	10 2 3
£1,500 3½ per cent. Registered War Stock at cost *(Value on Dec. 31st, 1940, £1,543)*	1,559 15 0
£500 National Defence Bonds at cost	500 0 0
Subscriptions Outstanding	20 0 0
Sundry Debtors on Sales Transactions	7 10 0
	£2,493 13 11

LIBRARY FUND ACCOUNT, 31st DECEMBER, 1940.

	£ s. d.
Balance at the beginning of the year	21 14 6
	£21 14 6

	£ s. d.
Balance:—	
Cash at Bank	21 14 6
	£21 14 6

LEON GASTER MEMORIAL FUND ACCOUNT, 31st DECEMBER, 1940.

	£ s. d.
Fund at the beginning of the year	240 11 4
War Stock Interest	8 1 0
Transfer from General Fund	5 0 0
	£253 12 4

	£ s. d.	£ s. d.
Expended during the year:—		
Premium for 1939/40		10 10 0
Balance:—		
Cash at Bank	6 9 2	
Invested in £230 3½ per cent. Registered War Stock at cost	236 13 2	
(Value on Dec. 31st, 1940, £237)		243 2 4
		£253 12 4

NATIONAL ILLUMINATION COMMITTEE FUND, 31st DECEMBER, 1940.

	£ s. d.
Fund at the beginning of the year	297 12 9
War Stock Interest	10 10 0
	£308 2 9

	£ s. d.
Balance:—	
£300 3½ per cent. Registered War Stock at cost *(Value on Dec. 31st, 1940, £309)*	304 8 6
Cash at Bank	3 14 3
	£308 2 9

INTERNATIONAL ILLUMINATION CONGRESS FUND (1931), 31st DECEMBER, 1940.

	£ s. d.
Fund at the beginning of the year	302 5 0
War Stock Interest	10 10 0
	£312 15 0

	£ s. d.
Balance:—	
£300 3½ per cent. Registered War Stock at cost *(Value on Dec. 31st, 1940, £309)*	304 8 6
Cash at Bank	8 6 6
	£312 15 0

We have examined the above accounts with books and vouchers, and certify same to be correct in accordance therewith, and that the Balance Sheet exhibits a true and correct view of the Society's affairs according to the information and explanation given to us.

Dated this 19th day of March, 1941.

ROBERT J. WARD & CO., *Chartered Accountants*,
Grosvenor House,
Park Lane, London, W.1.

REVISED BY-LAWS

(Presented at the Annual General Meeting held on May 13, 1941, and formally approved at the Extraordinary Meeting held at the E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, London, W.C., at 2.30 p.m. on Tuesday, June 24, 1941).

Definitions.

1. In these By-Laws, except where the context forbids, words importing males include females, and words implying the singular number include the plural number and vice versa.

"The Society" means The Illuminating Engineering Society incorporated in Great Britain.

The term "Members" when used without qualification includes Honorary Members, Corporate Members, Country Members, Associates, Students, and Sustaining Members, and such use does not connote membership of the Society within the meaning of the Articles of Association.

"The Secretary" includes the Honorary Secretary.

"Abroad" means outside Great Britain, Northern Ireland, the Isle of Man, the Channel Islands, and Eire.

Admission of Members.

2. The Council may elect as an Honorary Member anyone who satisfies the requirements of Clauses 7 and 9 of the Articles of Association and who has been nominated by the Council or proposed in writing by at least fifteen Members. Not more than one Honorary Member shall be elected in any one year, and the number of Honorary Members shall not at any time exceed six.

3. The Council may elect as a Corporate Member anyone who satisfies the requirements of Clauses 6 and 8 of the Articles of Association and who is duly supported in accordance with By-Law 8.

4. The Council may elect as a Country Member anyone who has attained the age of twenty-one years, who resides abroad, or not less than fifty miles from London and also not less than fifty miles from the headquarters of a recognised Local Centre, or not less than fifty miles from London and also outside the area assigned by the Council to a recognised Local Centre, and who is duly supported in accordance with By-Law 8.

5. The Council may elect as an Associate anyone who has attained the age of twenty-one years, who sympathises with the aims and objects of the Society, whose occupation is not mainly or primarily concerned with illumination, and who is duly supported in accordance with By-Law 8.

6. The Council may elect as a Student anyone who has attained the age of sixteen years but has not attained the age of twenty-five years, who is following a course of instruction approved by the Council, and who is duly supported in accordance with By-Law 8.

7. The Council may elect as a Sustaining Member any Society, Association, Local Authority, University, Technical Institution, Body, Company, or Firm which manifests interest in the work of the Society, and which is duly supported in accordance with By-Law 8.

8. An application for admission to the Society as a Corporate Member, Country Member, Associate, Student, or Sustaining Member shall be made in a form prescribed by the Council, and shall be supported by the recommendation of at least two Corporate Members in the following form or in such other manner as the Council may approve:—

"We hereby recommend (*here state name in full, date and place of birth, rank, profession, or business, and usual place of residence of the candidate*) who is personally known to us as a fit and proper person to become a (*here insert Corporate Member, Country Member, Associate, Student, or Sustaining Member*) of The Illuminating Engineering Society."

The names of those who have been admitted by the Council shall be published in the Transactions of the Society.

9. (i.) Country Members, Associates, Students, and Sustaining Members of the Society shall be entitled to all the privileges of membership except those confined to Honorary Members, Fellows, and Corporate Members, but they shall not be entitled to receive notice of or to attend or vote at General Meetings of the Society.

(ii.) A Country Member may at any time apply for admission as a Corporate Member and such an application shall not require to be supported as provided in By-Law 8. A Country Member who ceases to possess the qualifications requisite for admission as a Country Member shall cease to be a Member on the expiration of six months after the date on which he ceases to have these qualifications, unless in the meantime he has become a Corporate Member.

(iii.) A Student may, after attaining the age of twenty-one years, apply for admission as a Corporate Member or as an Associate, and such an application shall not require to be supported as provided in By-Law 8. A Student shall cease to be a Student of the Society on attaining the age of twenty-five years.

(iv.) A Sustaining Member shall be entitled from time to time to appoint any Corporate Member to be the representative of the Sustaining Member and to terminate any such appointment, but so that not more than one Corporate Member shall at the same time be the representative of the same Sustaining Member. Any such appointment or termination shall be by notice in writing to the Secretary of the Society. A Corporate Member shall not be required to pay any subscription which may become due while he is the representative of a Sustaining Member.

Fellows.

10. The Council may, after taking into consideration the recommendations of the Board of Fellows hereinafter mentioned, confer the honour of the Fellowship of the Society on any Corporate Member possessing the requisite qualifications.

11. A candidate for Fellowship shall be at least twenty-eight years of age and shall have been a Corporate Member of the Society for at least two years, provided that in exceptional circumstances the Council shall have power to reduce this period.

A candidate for Fellowship shall have held a responsible position requiring proficiency in the technical aspects of illumination for a period of not less than five years, and in addition shall possess at least one of the following qualifications:—

(a) The Final Grade Certificate in Illuminating Engineering of the City and Guilds of London Institute, or an equivalent qualification approved by the Council;

(b) A Science or Engineering Degree of a University

in the United Kingdom, or an equivalent qualification approved by the Council;

(c) The Corporate Membership of the Institution of Electrical Engineers or of the Institution of Gas Engineers;

(d) The achievement of an outstanding position in illuminating engineering as a result of wide experience or a specialised knowledge of some particular branch.

12. An application for the honour of Fellowship shall be made in the form prescribed by the Council and shall name three Corporate Members of the Society, preferably Fellows, who from personal knowledge of the applicant are prepared to support his application.

The Secretary shall obtain a written statement from each of the three Members so named of his opinion as to the suitability of the applicant to be accorded the honour of Fellowship. When the papers are thus completed they shall be forwarded in confidence to the Board of Fellows, appointed by the Council, whose names shall not be made public. It shall be the duty of the Board of Fellows to consider each application individually and make recommendations to the Council.

One-quarter of the number of members of the Board of Fellows shall retire annually in succession and shall not be eligible for re-election until one year has elapsed after the termination of their period of office.

The Council shall nominate from amongst those who have signified their desire for election as Fellows eight Corporate Members of appropriate standing who, until there shall be twelve Fellows, shall perform the duties of the Board of Fellows. Their names shall not be made public.

Certificates.

13. Subject to such regulations and on payment of such fees as the Council may from time to time prescribe, the Secretary shall issue to any Honorary or Corporate Member a certificate indicating the nature of his connection with the Society. Every such certificate shall remain the property of and shall on demand be returned to the Society, and shall contain the statement mentioned in Clause 12 of the Articles of Association.

Professional Use of Titles.

14. A Fellow shall be entitled to the exclusive use after his name of the initials "F.I.E.S.," to state that he is a Fellow of The Illuminating Engineering Society, and to adopt the initials "F.I.E.S." in connection with his professional or business activities.

The use of initials indicating connection with the Society shall be confined to Fellows and shall not be practised by Members of other grades.

Resignations.

15. A Member may resign from the Society by giving notice in writing to the Secretary at the registered office of the Society, but any such resignation shall be without prejudice to his obligation to pay to the Society any subscription due from him and in arrear at the time of his resignation.

A Fellow may resign his Fellowship by giving notice in writing to the Secretary.

Exclusion and Expulsion of Members.

16. In case any Member shall become bankrupt or lunatic, or shall be convicted of felony or any other criminal offence, the Council may decide that he shall cease to be a Member, and in such case they shall communicate such decision to him and he shall thereupon cease to be a Member.

17. Upon the receipt of a written request of not fewer than ten Corporate Members that, for cause definitely stated in detail, a Member should be expelled, the Council shall consider the matter and, if there appears to be sufficient cause, shall advise the Member concerned of the charges against him. The Member may then present a written defence and appear in person before a meeting of the Council, who, within two months, shall finally consider the case, and, if the defence be deemed not satisfactory, the accused Member shall be requested to resign, and, in the event of his refusing to do so, shall be expelled upon a two-thirds vote of the total membership of the Council.

Subscriptions.

18. The annual subscription to the Society shall be as follows:

	£	s.	d.
Fellows	2	12	6
Corporate Members (except Fellows and as provided by By-Law 9 (iv))	2	2	0
Country Members and Associates	1	1	0
Students (under 21 years of age)	0	10	6
Students (over 21 years of age)	1	1	0
Sustaining Members (minimum)	5	5	0

Honorary Members shall be exempt from all subscriptions.

19. Subscriptions shall become due on the 1st day of January in each year.

Members elected before the 1st day of July in any year shall pay the annual subscription for that calendar year, and those elected on or after the 1st day of July in any year shall for that calendar year pay half such annual subscription.

20. Members of the Illuminating Engineering Societies established in the British Commonwealth of Nations and in the United States of America may, at the discretion of the Council, be accorded the privileges of Associates temporarily during periods of residence in Great Britain and without payment of subscription.

21. The annual subscriptions of Corporate Members who have attained the age of thirty-five years may be compounded by payment of the following sums:—

	35—44 years of age	Over 45 years of age.
Fellows	30 guineas	25 guineas
Other Corporate Members	25 „	20 „

A member who has already compounded for his subscription as a Corporate Member may, on becoming a Fellow, either pay an additional annual subscription of half a guinea or compound for the additional subscription by a supplementary payment of five guineas.

22. Any person who was a Member or Associate of the Illuminating Engineering Society that was the predecessor of the Society and who compounded his subscription by payment to such predecessor shall have the same rights and privileges as if he had compounded by payment to the Society.

23. If the annual subscription of any Member shall be in arrear for three months, the Secretary shall give notice thereof to him, and if the subscription shall continue in arrear at the expiration of three months after such notice, the Council, having thereafter given the defaulting Member three months' notice of their intention, shall have power to strike his name off the register, and he shall thereupon cease to be a Member of the Society, but shall remain liable for any arrears of subscription which shall be due at the date of cessation of membership.

24. A person who has ceased to be a Member under the last preceding By-Law may be reinstated by the Council

and be permitted to retain his original date of election upon payment of all outstanding arrears of subscription, being then entitled to such copies of the Transactions and of the Official Journal of the Society as he would have received if he had not ceased to be a Member, subject to such copies being in stock.

25. The Council may in any special case, where, in their opinion, it is desirable to do so, reduce or remit the annual subscription, or any arrears of annual subscription of any Member.

Where any Member has rendered useful service to the Society over a long period of years, the Council may, at their discretion, remit all further subscriptions.

Publications.

26. Such papers read at Sessional Meetings of the Society and discussions thereon, announcements of admissions to membership, and other notes on the papers or proceedings of the Society as the Council shall direct shall appear in the Transactions of the Society, which shall be circulated to all Members entitled thereto.

Supplementary notes on meetings of the Society and its aims and objects shall appear in "Light and Lighting," published by the Illuminating Engineering Publishing Company, Ltd., which shall serve as the Official Journal of the Society and shall likewise be circulated to all Members entitled thereto, subject to such arrangements between the Society and the Illuminating Engineering Publishing Company, Ltd., as the Council shall approve.

27. Papers read and lectures delivered before the Society shall not be published in full elsewhere than in the Transactions or in the Official Journal of the Society, without permission of the Council. Abstracts of lectures, papers and other contributions may only be published after the actual date of reading or delivery.

28. Every paper presented to the Society and accepted for reading or for publication in full or in abstract, and every paper read before the Society or a Local Centre, and the copyright thereof, shall be the property of the Society. The Council, in such cases as they may think fit, shall have power to release or surrender the rights of the Society in respect of any such paper or the copyright thereof. The right of publishing all such papers and the reports of the proceedings and discussions at meetings of the Society and of the Local Centres shall be reserved to the Council, who may, as they think fit, give their consent to publication in approved cases.

Sessions and Meetings.

29. The Session of the Society shall begin on or about the by such notice and in such manner as the Council shall from the 1st day of June in the following year.

30. In addition to General Meetings of the Society Sessional Meetings shall be held at such places and at such times as the Council may appoint for the reading and discussion of papers on illuminating engineering or allied subjects, and for lectures and discussions on those subjects. The Council may also arrange for other meetings to be held for the dissemination of knowledge of illuminating engineering and allied subjects, and the discussion of papers thereon.

31. Such Sessional and other meetings shall be summoned by such notice and in such manner as the Council shall from time to time think fit, and the Council shall determine the conditions of admissions to such meetings and the manner in which they shall be conducted.

32. Members shall have the privilege of introducing visitors at each Sessional Meeting of the Society and at such other meetings as the Council shall decide, by writing their names in a book provided for that purpose, or supplying them with admission tickets to be obtained from the Secretary.

33. Matters relating to the direction and management of the Society shall not be discussed at any meeting other than a General Meeting of the Society.

The Library.

34. The collection of books on illumination and allied subjects, the property of the Society, shall be available for inspection or loan to all Members on such terms as may be determined by the Council, who, in the event of any volume not being returned within the prescribed period, shall take steps to recover the volume or its value from the Member concerned.

Awards.

35. The Leon Gaster Memorial Premium, consisting of Ten Guineas and a Certificate recording the award, shall be awarded annually for the best contribution submitted to and published by the Society during the Session. Decisions in regard to the award shall rest with the Council, by whom it may be withheld in the event of no contribution of sufficient merit being submitted in any Session.

36. The Silver Jubilee Commemoration (1934) Award shall be awarded annually to any Member who is under the age of twenty-five years on the date of his qualification for the Award, and shall consist of Five Guineas and a Certificate recording the Award. The qualification is the accomplishment of any of the following tasks: (1) The presentation in writing to any Technical Society or Association approved by the President of a paper dealing with the theory or practice of illuminating engineering; or (2) the design and/or construction of a novel instrument or appliance for use in connection with any application of or research concerning illumination; or (3) the carrying out by the applicant of an investigation beneficial to illuminating engineering.

In the event of no application of sufficient merit being received, the Council shall have power to withhold the Award or to apply it for any other object in furtherance of the aims and objects of the Society.

Notices.

37. Any notice may be served or any communication may be sent by the Society or the Council or by the Secretary of the Society upon or to any Member, either personally or by sending it through the post in a prepaid letter addressed to such Member at his address as registered in the books of the Society.

38. Any notice or communication, if served or sent by post, shall be deemed to have been served or delivered on the day following that on which the same is posted, and in proving such service or sending it shall be sufficient to prove that the letter containing the notice or communication was properly addressed and put into a post office as a prepaid letter.

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THE RECOGNITION OF COLOURED LIGHT SIGNALS

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(Delivered on Tuesday, February 11th, 1941).

SUMMARY.—Part 1 describes the construction and calibration of a laboratory apparatus which combines light beams transmitted through colour filters in such proportions as to reproduce the intensity and energy distribution of all the coloured light signals generally used in practice.

Part 2 discusses the technique of signal colour recognition and gives the results of over 40,000 observations in the form of charts on which are drawn contours of the frequency of recognition of the simple colours under different conditions of illumination, range of possible colours, etc. The significance of these contours is briefly discussed, with a view to stating physical limits within which signal colours should lie.

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PART I.—AN APPARATUS FOR PRODUCING LUMINOUS COLOURS.

1. Introductory.

The apparatus to be described was made in order to provide a range of coloured light signals for an investigation into recognition. The coloured light required to be in a form suitable for observation under conditions comparable with those governing light signals at night and the range of colours had to extend over the whole region of the colour triangle in which the common signalling colours lie. The requirements of the apparatus may be summarised as follows:—

1. The calibration must be stable and easily checked. Local, relative errors are more serious than absolute errors.
2. The adjustments for changing the colours must be rapid and fool-proof.
3. The spectral distribution of energy in the colours must be smooth and similar to that of the colour filters used in full-scale signalling practice.
4. The luminous intensities of the colours must be equal.
5. The colours must be seen as point sources of light.

2. Experimental Methods.

It is of interest to consider some of the methods available and their relative accuracy and convenience.

The method which is simplest in general outline is to employ a large number of glass or gelatine filters whose colour can be measured when associated with a light source operating at several different colour temperatures, but in practice this method is somewhat complex. A large number of glasses is required, involving tedious calibration with relatively large errors, and the adjustments needed to maintain constant luminous intensity are difficult.

A somewhat similar method is to select and recombine different regions of the spectrum in varying degrees of intensity, as an extension of the Wright[1] or the Houston[2] Colorimeters. This has the disadvantage of extreme difficulty in constructing the apparatus if the full requirements of the experiment are to be fulfilled.

A standard visual trichromatic colorimeter such as the Guild[3] may be used, so that the exit pupil forms the colour to be observed. This permits of easy and accurate calibration and simple adjustment, but has the fundamental disadvantage that if a large area of the colour chart is to be covered the three primaries must be highly saturated and the combined colour will possess an irregular spectral distribution of energy. Owing to chromatic aberration in the eye at large pupil sizes, the observer tends to focus on the brightest primary to the detriment of the other two component primaries, and thus receives a misleading impression of the combined colour.

A colorimeter may be constructed of the monochromatic-plus-white type similar to the Nutting[4] colorimeter, except that the monochromatic stimulus may be replaced by a series of light beams, passing through highly saturated colour filters. If these filters have similar properties to those used in practice, the difficulty of chromatic aberration may not be acute, but there will generally be a difference between the spectral composition of the colour and that of the glass used in practice. Detailed adjust-

ments are necessary to maintain constant luminous intensity.

A more complex method is to employ a range of trichromatic colorimeters, each covering a small triangular area of the colour chart, and so to attempt to match the practical spectral composition in much the same way as in the Donaldson[5] 6-primary colorimeter. The complexity of the method lies in the need for accurate calibration and complete mixing of the range of primary stimuli, but once this is achieved the control is a simple matter, as in the Guild trichromatic colorimeter above. A development of this method has been adopted for the present work, in which combinations of eleven primaries are used to give twelve triangles covering the useful area of the colour chart.

3. Design and Construction.

The principle is to build up the colour required by combining adjustable proportions of strongly coloured beams of light, in such a way that the energy distribution in the combined colour is comparable with that which would be given by an efficient glass filter of the same colour. A preliminary experiment[15] was made in the construction of a colour mixer with four green primary beams giving a range of colours in the green area of the colour triangle. This gave satisfactory results, and the larger apparatus embodying eleven primaries was built on the same principle. The assembly is shown diagrammatically in Fig. 1.

Light from a concentrated filament lamp was rendered parallel by a lens and passed through a master stencil with eleven apertures on to eleven glass colour filters. The coloured beams were collected by a second lens and brought to a common focus where they were mixed to form the colour to be observed. A test stencil could be placed on the master stencil to select the desired proportions of the light beams.

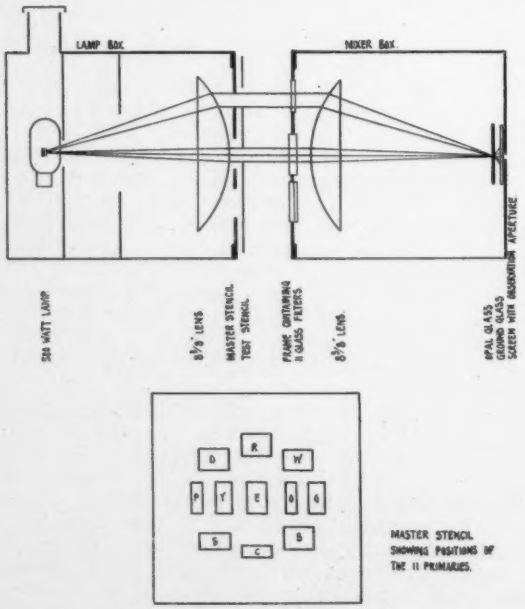


Fig. 1. Diagram of Colour Mixer.

The light source was a 230v/500w Class A1 gas-filled projector lamp, operated at 200 volts and so screened that no reflected images from the bulb surfaces could be seen from the collimator lens. The nearest colour temperature of the light emerging from the colour mixer without the glass colour filters in place was 2360°K.

The collimator lens was an 8⅜ in. diameter by 11½ in. focus "Truvex" which is free from spherical aberration and substantially colourless. The lamp and lens were mounted in a blackened box with screened ventilation.

The parallel beam from the lens passed through the master stencil and a test stencil and the selected rays fell on glass filters on the end of the mixer box. The apertures in the stencils were cut in accordance with the colour required to be given by the apparatus, and are discussed in Section 4 (2) below. The glass filters ranged from red to blue, with white and purple included, and are described in detail in Section 4 (1) below.

The condenser lens in the mixer box was identical with the collimator and concentrated the light on to a mixing device. Initially this was a 6 in. Ulbricht sphere, with one aperture large enough to admit all the coloured images of the filament lamp and a second aperture at right-angles to it which acted as a secondary source of light whose colour and intensity were controlled by the test stencil. With the 11-primary mixer the brightness of the sphere surface was 0.144×10^{-5} candles/cm², which was barely sufficient to give the desired range of intensity from a small viewing aperture, and experiments were made to find an equally efficient mixing device giving a higher brightness. It was found that a piece of flashed opal glass placed at the focus of the condenser lens scattered the coloured beams equally and could be made to provide adequate mixing.

The images of the light source given by the eleven primary beams were superimposed on the flashed opal glass and the fine structure of the image of the filament coils could be further broken up by viewing it through ground glass adjacent to the opal. The lenses were free from spherical aberration, but the astigmatism was dependent on the dominant wavelength of the light and thus only the centre of the image received light which was a complete mixture of all the primary beams. The degree of mixing was checked under a variety of conditions of focal position, separation of the diffusing glasses and relative openings of the stencil apertures, and ample tolerance was found to ensure perfect mixing and constant contribution from the eleven primary beams. The brightness of the central area of the patch of light was 0.92×10^{-3} candles/cm² for the equivalent of one primary beam.

An opaque screen close to the glass contained a small aperture which formed the test colour to be observed, and a slowly rotating shutter completed the optical system.

The observer was in another room in which the aperture of the colour mixer was the only light,

whilst the operator had ample illumination for rapid and accurate working of the mixer.

Any required colour was produced by combining the appropriate proportions of the nearest three primaries and thus the colour triangle was divided into a series of small triangles whose apices were defined by the trichromatic coefficients of the primaries. Once these coefficients were accurately known, experimental errors in the proportions of the mixture or calibration errors in their relative luminosities would lead to second-order errors in the coefficients of the combined colour, as they would only displace the colour within the small triangle formed by the three primaries in use. The primaries were given by actual glasses of the type used in signalling, so that the combined colour would be closely comparable with practical conditions, but for this reason it was not possible to cover the whole area within the spectrum locus. Highly saturated blues and greens cannot be obtained with a sufficiently high total transmission and there is a considerable range of highly saturated colours from 400 mμ to 520 mμ which cannot be satisfactorily investigated with this apparatus. This limitation was not a serious disadvantage as this area of the colour chart is not used in general signalling practice.

An accessory was added towards the end of the observations to carry out tests on a sodium vapour discharge lamp. Another aperture was mounted close to the colour mixer aperture and illuminated to the appropriate brightness by light led along a glass rod from a 100 watt sodium lamp.

4. Calibration.

There is necessarily a great amount of calibration to be performed in order to reduce each source of error to a minimum in turn and to permit accurate control and measurement of the colour mixtures. The eleven primaries were cross-checked in considerable detail and the probable effects of various errors have been deduced.

(1) The Glass Filters.

The eleven filters used for the primaries were as shown in Table 1.

The properties of these filters are given in Tables 2 and 3.

The first stage in the calibration was the measurement of the spectrophotometric transmission given in Table 2 from 400 mμ to 750 mμ, and the calculation of the trichromatic coefficients and total transmissions when each glass was combined with a light source at 2848°K (C.I.E. Illuminant A) and at 2360°K (standard signalling illuminant).

Colorimeter measurements[6] were then made on each primary filter with Illuminant A in comparison with a similar glass which had been spectrophotometrically calibrated by the N.P.L. Illuminant A was used, as the 2360°K source gave insufficient brightness in the colorimeter field for accurate measurement. Photometer bench measurements against similar calibrated glasses were used to give further values for the total transmission.

TABLE 1.

Glasses used as primary filters.

Reference letter	Name	Ref. in Chance catalogue	Description
C	Crimson	1	Dark selenium ruby
R	Red	2 & 11	Light selenium ruby and a neutral glass
O	Orange	4 & 11	Cd-Se sheet glass and a neutral glass
Y	Yellow	16 & 11	Cadmium yellow glass and a neutral glass
E	Emerald	5	Chromium green
G	Green	6 & 4	Copper green combined with a Cd-Se yellow
S	Signal green	6	Copper green
B	Blue	—	Cobalt blue
P	Purple	—	Combination of light cobalt blue and gold ruby
W	White	10	Neutral tinted
D	Daylight	9 & 11	½-watt-to-daylight correction filter combined with a neutral glass

(2) The Assembled Apparatus

The glass filters were mounted in the mixer and each measured in turn by sighting the colorimeter on the exit aperture. Check measurements were made on combinations of two and three primaries and figures were obtained for their trichromatic coefficients and relative brightness. The apertures in the master stencil were adjusted to give uniform brightness and the measurements repeated by five experienced observers.

The calculated and observed results for Illuminant A were in good agreement and comparison between the calculated results for 2360°K and the observed results in the mixer permitted small errors in the latter to be smoothed out to give the figures finally adopted for the trichromatic coefficients of each primary. The figures obtained in the successive stages of the calibration are given in Table 3.

Similar comparison between the 2360°K calculations of total transmission and the photometer bench measurements on the one hand and the direct colorimeter measurements on the mixer and the areas of the stencils on the other hand enabled small adjustments to be made to the master stencil to give the same effective brightness for every primary. This adjustment would take account of the varying transmission, magnification and flux density across the two lenses and also of any residual imperfections in the mixing device.

The whole mixer was first roughly and then carefully calibrated in this way, the second calibration being done by three to five observers, and a good consistency was obtained.

The calibrations described have referred only to the overall colour and brightness of each primary. A colour variation was expected across the lens, due to chromatic aberration or selective absorption, but measurements of white light and of the purple primary in the different stencil apertures gave no

TABLE 2.
Spectrophotometric Data for Primary Glasses.

Wave-length	Crimson	Red	Orange	Yellow	Emerald	Green	Signal Green	Blue	Purple	Neutral White	Daylight
mμ											
400						0.5	14.6	72.5	11.5	7.6	11.9
410						0.6	15.6	72.0	11.3	7.0	11.8
420					0.1	0.8	16.9	71.0	11.0	5.2	11.6
430					0.1	1.4	18.9	69.7	10.5	3.2	11.5
440					0.2	2.3	20.9	67.8	9.8	2.4	11.3
450					0.3	3.5	23.3	61.5	8.7	2.4	11.2
460					0.5	4.8	26.5	53.5	7.5	3.0	11.1
470					1.0	6.6	29.7	45.0	5.9	3.6	11.0
480					1.9	8.3	31.4	34.5	3.7	4.2	11.0
490			0.1		4.1	9.7	31.6	24.5	1.9	4.5	11.0
500			0.4	0.1	7.6	10.1	30.4	17.5	0.7	4.8	10.4
510			0.8	1.7	12.8	9.9	26.5	12.0	0.3	4.8	9.9
520			1.4	4.4	18.2	8.6	20.5	8.5	0.2	4.7	9.8
530			1.9	6.5	19.0	7.1	14.0	6.1	0.2	4.0	10.0
540			2.5	8.1	18.4	5.5	8.4	6.0	0.2	4.0	9.8
550			3.5	9.1	14.4	3.4	4.2	7.0	0.2	4.2	9.2
560			4.8	9.4	7.8	1.9	1.6	10.0	0.4	5.2	7.9
570		0.1	5.5	9.0	4.5	0.8	0.1	7.0	0.9	5.2	6.1
580		0.3	7.3	8.6	2.4	0.4		3.0	1.0	4.7	4.8
590		1.8	7.6	8.8	1.1	0.2		1.2	0.9	3.6	3.6
600		7.8	8.2	9.8	0.3	0.1		0.8	0.9	3.2	3.7
610	0.1	14.8	8.3	9.5	0.1			0.9	1.2	3.0	3.2
620	8.2	18.5	8.0	8.6				1.1	1.5	3.0	2.6
630	46.1	18.5	7.0	8.0				1.0	1.5	2.9	2.1
640	77.0	18.5	7.1	8.0				0.8	1.5	2.8	2.0
650	80.8	20.5	8.8	9.8				0.7	1.4	3.0	2.1
660	81.0	24.5	11.8	13.0				0.9	2.0	4.7	2.5
670	81.0	31.4	16.1	17.8				1.6	3.7	8.6	3.3
680	81.0	38.4	23.5	23.5				4.6	8.0	15.6	5.0
690	81.0	45.6	30.4	32.0				16.0	20.5	27.2	7.2
700	81.0	52.5	35.8	37.0				37.5	35.0	36.0	8.3
710	81.0	53.0	37.7	37.8				53.0	50.0	43.8	8.5
720	81.0	53.0	38.6	38.0				67.0	60.0	46.3	8.5
730	81.0	53.0	38.8	38.0				75.0	66.7	47.4	8.4
740	81.0	53.0	38.6	38.0				78.0	69.4	48.0	8.2
750	81.0	53.0	38.3	38.0				79.7	70.5	48.6	7.9

TABLE 3.
Colour and Transmission of Primary Glasses.

GLASS	TRANSN. with 2848°K (calculated)	COLOUR with 2848°K (calculated)		COLOUR with 2360°K (calculated)		COLOUR with 2848°K (measured)		COLOUR in Colour mixer (measured)	
		x	y	x	y	x	y	x	y
Crimson	7.11%	0.719	0.281	0.719	0.281	0.721	0.279	0.721	0.279
Red	4.84%	0.691	0.309	0.693	0.307	0.690	0.309	0.697	0.302
Orange	5.51%	0.590	0.407	0.604	0.394	0.589	0.406	0.599	0.396
Yellow	8.17%	0.544	0.451	0.562	0.434	0.552	0.444	0.560	0.436
Emerald	6.77%	0.249	0.679	0.261	0.677	0.241	0.691	0.275	0.670
Green	2.56%	0.162	0.489	0.173	0.526	0.148	0.493	0.189	0.555
Signal Green ...	5.11%	0.126	0.318	0.127	0.366	0.133	0.332	0.148	0.375
Blue	5.75%	0.203	0.196	0.234	0.246	0.203	0.185	0.250	0.258
Purple	0.95%	0.365	0.181	0.450	0.230	0.373	0.177	0.457	0.233
Daylight	6.31%	0.325	0.416	0.367	0.444	0.330	0.390	0.357	0.439
Neutral White ...	4.24%	0.447	0.429	0.488	0.430	0.440	0.411	0.483	0.444

indication of any appreciable variation. It was found that the effective brightness across the lens face varied between 0.84 and 1.00, being substantially constant in any one zone but falling from the centre to the periphery. This intensity variation was overcome by suitable arrangement of the stencil apertures, as follows:—

The apertures were all rectangular, the two pairs of opposite sides being formed by super-position of test stencils on the master stencil. In the master stencil, the width of each of the eleven primary apertures was made inversely proportional to the transmission, flux density, etc., in the way described above, and the length was made 3.00 cm. In the test stencils the apertures were so cut that their widths were integral multiples of 0.50 cm. and their lengths greater than the widths in the master stencil. The test stencil was placed over the master stencil so that the lengths of the two overlapping apertures were at right angles, and thus the area through which the light could pass was not dependent on the accurate location of the test stencil. Moreover, the apertures in the test stencil only required two straight edges at the correct separation, eliminating the need for careful cutting of the two transverse edges and four corners and the random errors which they might introduce.

The apertures in the master stencil were cut with the 3 cm. length substantially perpendicular to the radius of the lenses, so that there was no appreciable variation of flux density, etc., along it, and thus the brightness of a primary selected by the test stencil was not dependent on its location. The stencils were cut so that they would not fit wrong way round or so seriously displaced that light was transmitted to fall on the wrong glasses.

The eleven primaries were used to divide the colour chart into twelve small triangles, as shown in Fig 2. This diagram is the basis of the diagrammatic representation of the results in Part II. of this paper, and it will be seen that these diagrams show the spectrum locus, with a scale of wavelengths in mμ, and the locus of Planckian whites from 1900°K to 6500°K, plotted on the C.I.E. basis(7). Fig. 3 shows the scale of the white locus. Eleven of the small triangles were drawn in simple rotation to cover the whole available

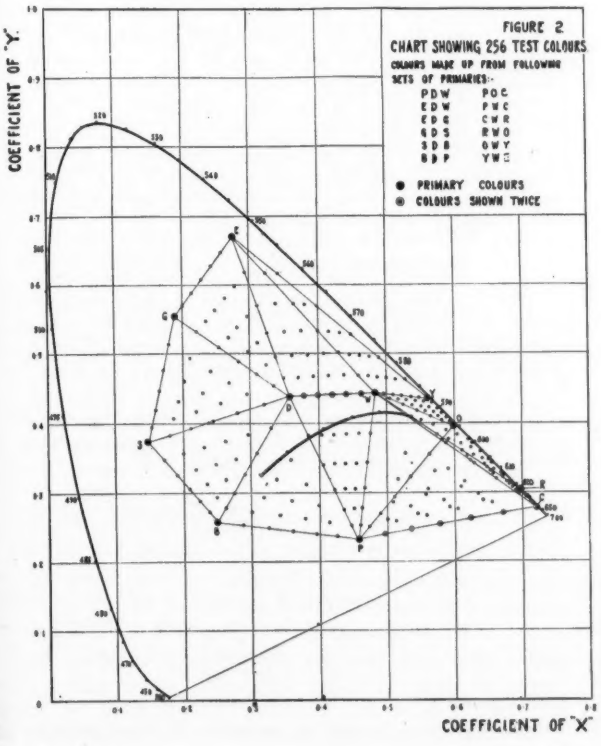


TABLE 4.

Trichromatic Coefficients for 256 test colours.

Stencil	x	y	Stencil	x	y	Stencil	x	y
1	0.563	0.354	36	0.422	0.340	71	0.532	0.411
	.534	.321		.438	.340		.714	.286
	.510	.293		.454	.341		.685	.306
	.489	.270		.470	.341		.652	.330
5	.472	.250	40	.437	.304	75	.617	.353
	.626	.370		.452	.304		.574	.383
	.590	.333		.466	.305		.710	.290
	.560	.304		.462	.277		.680	.311
	.534	.278		.450	.276		.647	.335
10	.513	.257	45	.459	.253	80	.610	.359
	.495	.240		.495	.240		.706	.294
	.650	.347		.501	.261		.676	.314
	.613	.315		.507	.286		.643	.338
	.583	.288		.516	.317		.701	.298
15	.557	.266	50	.527	.356	85	.671	.319
	.535	.247		.540	.404		.684	.314
	.671	.327		.535	.247		.657	.332
	.634	.298		.544	.269		.627	.352
	.603	.275		.556	.297		.591	.376
20	.577	.254	55	.570	.329	90	.551	.403
	.690	.309		.588	.371		.504	.435
	.654	.284		.577	.254		.670	.328
	.622	.262		.591	.278		.640	.348
	.706	.294		.608	.308		.609	.369
25	.670	.270	60	.629	.342	95	.568	.397
	.378	.439		.622	.262		.524	.427
	.399	.440		.640	.287		.655	.343
	.420	.441		.663	.320		.624	.363
	.441	.442		.670	.270		.587	.389
30	.462	.443	65	.695	.297	100	.544	.418
	.402	.382		.718	.282		.638	.358
	.421	.383		.690	.301		.603	.383
	.439	.384		.657	.325		.564	.410
	.458	.385		.624	.346		.620	.376
35	.475	.386	70	.583	.375	105	.581	.403

TABLE 4 (continued)

Stencil	x	y	Stencil	x	y	Stencil	x	y	
106	0.593	0.402	156	0.407	0.499	206	0.179	0.384	
	.575	.410		.384	.498		.211	.394	
	.557	.417		.360	.497		.244	.404	
	.537	.426		.337	.496		.280	.415	
110	.517	.434	160	.375	.532	210	.318	.427	
	.496	.442		.350	.531		.153	.396	
	.587	.408		.325	.530		.186	.407	
	.568	.416		.337	.571		.220	.418	
	.550	.424		.311	.570		.255	.429	
115	.529	.433	165	.294	.617	215	.294	.442	
	.509	.441		.447	.253		.158	.421	
	.581	.414		.436	.276		.193	.433	
	.561	.423		.422	.304		.229	.445	
	.542	.431		.405	.339		.269	.458	
120	.522	.439	170	.385	.382	220	.164	.448	
	.574	.421		.425	.237		.203	.461	
	.554	.430		.413	.257		.241	.475	
	.535	.438		.398	.281		.171	.477	
	.567	.429		.379	.311		.212	.494	
125	.547	.437	175	.358	.347	225	.180	.514	
	.527	.463		.393	.241		.223	.532	
	.513	.464		.377	.262		.254	.510	
	.500	.466		.358	.287		.283	.490	
	.486	.467		.336	.318		.309	.472	
130	.472	.468	180	.359	.245	230	.334	.455	
	.490	.494		.340	.266		.201	.572	
	.475	.495		.317	.293		.236	.547	
	.460	.497		.324	.249		.268	.524	
	.445	.499		.287	.254		.296	.503	
135	.431	.501	185	.301	.272	235	.323	.485	
	.448	.528		.261	.277		.214	.590	
	.432	.529		.275	.299		.249	.563	
	.416	.532		.290	.325		.283	.539	
	.400	.534		.308	.356		.310	.516	
140	.459	.470	190	.330	.393	240	.228	.608	
	.399	.569		.238	.272		.263	.580	
	.380	.571		.249	.293		.296	.554	
	.365	.573		.262	.318		.243	.628	
	.341	.616		.277	.348		.278	.598	
145	.323	.617	195	.295	.384	245	.258	.648	
	.462	.443		.224	.288		.148	.375 S	Primaries
	.441	.442		.234	.312		.250	.258 B	
	.420	.441		.247	.340		.457	.233 P	
	.399	.440		.262	.374		.560	.436 Y	
150	.378	.439	200	.208	.306	250	.275	.670 E	Margins
	.436	.469		.218	.333		.599	.396 O	
	.414	.468		.230	.365		.189	.555 G	
	.392	.467		.191	.326		.357	.439 D	
	.370	.466		.200	.356		.483	.444 W	
155	.348	.466	205	.172	.348	255	.697	.302 R	
						256	.721	.279 C	

area of the chart, and the twelfth (CPO) to overlap in the red-purple region so as to give a greater concentration of test colours and a check on the calibration and spectral energy composition of the combined colours. The triangle PWO was not used as no signalling colours lie in this area.

Within each triangle colours could be formed by mixture of the three primaries, and the test stencils were cut with multiples of 1/6 of each (0.5 cm.), keeping the sum of the widths constant at 3.0 cm. Thus a colour could be made of 1/6 R + 2/6 W + 3/6 O, or 4/6 G + 1/6 D + 1/6 S, and so on. This gave five intermediate colours in each side of each triangle and ten colours distributed evenly within each triangle, making 256 colours in all. This required 256 stencils, made from stiff black paper and cut by a tool giving a multiple of 0.5 cm. The trichromatic coefficients of the combined colours are given in Table 4, and were calculated as shown therein.

Consider three primaries U, V and W, whose unit equations of trichromatic coefficients are $(x_1\ y_1\ z_1)$, $(x_2\ y_2\ z_2)$ and $(x_3\ y_3\ z_3)$ respectively. As their luminosities are equal, the luminosity equations may be re-written:

$$U = x_1X + y_1Y + z_1Z$$
$$V = k_2x_2X + y_1Y + k_2z_2Z$$
$$W = k_3x_3X + y_1Y + k_3z_3Z$$

where $k_2 = y_1/y_2$ and $k_3 = y_1/y_3$.

If these primaries are combined in the ratio $\alpha : \beta : \gamma$, the luminosity equation of the combined colour will be:

$$C = (\alpha x_1 + \beta k_2x_2 + \gamma k_3x_3) X + (\alpha + \beta + \gamma) y_1Y + (\alpha z_1 + \beta k_2z_2 + \gamma k_3z_3) Z.$$

When this is reduced to a unit equation, it gives the C.I.E. trichromatic coefficients of the combined colour.

In practice, α, β and γ were multiples of 1/6 and the coefficients k_2x_2, etc., were known. A table of the luminosity coefficients of 1/6 to 5/6 units of each primary was drawn up and the sum of the coefficients appropriate to the proportions of the mixture gave the luminosity equation of the combined colour by mental arithmetic. This was converted to the unit equation by slide rule. A check on the calculation was provided by the diagram (Fig. 2), in which all the combined colours in one of the triangles lie on series of intersecting straight lines and individual errors are immediately noticeable.

(3) The Estimation of Errors.

Consider two primaries A and B, whose unit trichromatic coefficients are (x′, y′, z′) and (x″, y″, z″) respectively, where $x+y+z=1$. At equal luminosities the coefficients for B may be written (x″y′/y″, y′, z″y′/y″).

If we combine a fraction α of A with $(1-\alpha)$ of B, we obtain a colour C on the line joining A and B, whose unit trichromatic coefficients are:

$$x = \frac{\alpha x' + k(1-\alpha)x''}{\alpha + k(1-\alpha)}$$

$$y = \frac{y'}{\alpha + k(1-\alpha)}$$

$$z = \frac{\alpha z' + k(1-\alpha)z''}{\alpha + k(1-\alpha)}$$

where $k = y'/y''$.

Suppose there were an error e in the amount of

the colour A, so that the actual mixture was $(1+e)\alpha$ of A and $(1-\alpha)$ of B. The combined colour C would be given by:

$$x_1 = \frac{(1+e)\,\alpha\,x' + k\,(1-\alpha)\,x''}{(1+e)\,\alpha + k\,(1-\alpha)} \quad \text{etc.}$$

The error in the X-coefficient is $\delta x = x_1 - x$, and its ratio to the difference between A and B may be written as:

$$\frac{\delta x}{\triangle x} = \frac{x_1 - x}{x'' - x'} = \frac{k\,e\,\alpha\,(1-\alpha)}{[(1+e)\,\alpha + (1-\alpha)\,k]\,[\alpha + k\,(1-\alpha)]} = E$$

similarly $\delta y / \triangle y = \delta z / \triangle z = E = \delta l / \triangle l$, where l is the linear distance from A to B. Thus the ratio E is the error in the combined colour, expressed as a fraction of the distance between the primaries.

This error will be zero at $\alpha = 0$ or $\alpha = 1$, corresponding to the primaries alone. It will be a maximum when

$$\alpha = \frac{k^2 \pm k\sqrt{1+e}}{k^2 - (1+e)} \text{ or } \alpha = \frac{k}{k + \sqrt{1+e}}$$

and the corresponding maximum value of E is:

$$E_{max} = \frac{\sqrt{1+e} - 1}{\sqrt{1+e} + 1}$$

Where e is small, E_{max} is less than $e/4$.

Thus the maximum error in the trichromatic coefficients caused by an error in the amount of one of two primaries is independent of the position of the primaries and depends only on the fractional error in the amount of one primary and on the separation between the primaries. This argument can readily be extended to the combination of three primaries.

In the particular case with which we are concerned the maximum error which can occur will be the product of E as determined above and the length of the longest line that can be drawn in the elementary triangle through the colour concerned.

The errors in the cutting of the stencils and in the transmission factors of the glass filters both contribute to the same type of error. The average error in the stencil is less than $e=0.007$, whence $E_{max}=0.0017$. The average error in the primary brightness is less than $e=0.06$, whence $E_{max}=0.015$. The length of the longest line in the various elementary triangles described varies from 0.125 units for the triangle YWO to 0.369 units for the triangle PWY, with an average of 0.254 units. The greatest error which can occur in the average triangle is therefore 0.0004 for the stencil errors and 0.004 for the luminosity errors.

(4) The Effect of Errors in the Calibration

(4a) ***Local Errors.***—These are errors whose effect would only be to displace the trichromatic coefficients of the combined colour within the triangle formed by the primaries contributing to it.

The widths of the test stencil apertures.—The tools which were made to cut the stencils were found to give apertures accurate to 0.1 mm. In extreme cases this corresponds to an error of nearly 0.002 in the trichromatic coefficient of the combined colour, but in most cases is less than 0.001.

Transmission factor of glasses.—The probable error of the figures in Table 3 is $\pm$ 0.3% in the total percentage transmission. Calculation of extreme cases showed that this corresponds to a probable error of 0.002 in the trichromatic coefficients of the combined colour and to a maximum error less than 0.005. The effect on the brightness of the combined colour was negligible.

Variation of colour across lens.—This is less than $\pm$ 0.002 when measured with the purple primary filter across the whole width of the lens and is negligible over the area of one primary filter.

Variation of flux density across lens.—This amounts to $\pm$ 7.5% from the edge to the centre, and the stencils were so cut that it was negligible over the area of one primary filter.

(4b) ***Major Errors.***—These are errors which would involve the primary colours and which might displace a large number of combined colours.

Colour coefficients of primaries.—The positions of the corners of the elementary triangles were liable to an error of $\pm$ 0.005 in the trichromatic coefficients of all except the green primary, which gave a probable error of 0.010.

Variation of voltage and colour temperature of lamp.—The maximum voltage variation during a run was less than 0.5%. This corresponds to 9°K in the colour temperature of the lamp, or a round figure of 0.001 in the trichromatic coefficients of the primaries. The effect on the brightness of the combined colour was negligible.

The sum of these errors is not negligible, but the large number of points on the colour chart renders the rare case in which they all reinforce each other, statistically unimportant.

Check measurements of intensity level were made during the experimental observations and at the end.

5. Spectral Energy Distribution in Combined Colours

Any given colour may be produced by an infinity of different energy distributions, but in practice the distribution of energy is closely controlled by the choice of colouring materials in the coloured glass filter. It is claimed for this colour mixer that the energy distribution in the mixed colour is smooth and is a close approximation to that given by a glass filter of the same colour, so avoiding sharp discontinuities in the energy distribution curve and the variable effects of chromatic aberration in the dark-adapted eye. Table 5 gives data relating to three combined colours, chosen to match the Ministry of Transport light limit green by a mixture of G, S and D, and to match a typical gold ruby by mixtures of R, C and W and of O, C and P. The data in Table 5 is in the form of percentage transmission at each wavelength for combination with Illuminant A

(2848°K), and it will be seen that a satisfactory energy match is obtained in each case.

TABLE 5.
Energy distribution data for typical mixed colours.

λ (mμ)	Ministry of Transport light limit green glass	Combination of G, S & D	Typical gold ruby glass	Combination of R, C & W	Combination of O, C & P
400	23.0	25.5	8.2	5.4	3.5
420	32.5	27.3	7.5	3.7	3.3
440	41.2	32.8	7.5	1.7	2.9
460	48.0	41.4	6.0	2.2	2.3
480	52.2	52.0	3.0	3.0	1.1
500	51.8	55.0	0.7	3.4	0.6
520	45.5	44.8	—	3.4	1.3
540	33.0	30.0	1.5	2.9	2.4
560	20.2	15.5	7.5	3.7	4.5
580	10.4	7.0	16.7	3.6	6.9
600	4.3	5.0	25.5	6.3	7.7
620	1.8	3.4	33.9	13.0	10.1
640	0.7	2.6	42.7	30.3	29.8
660	0.2	3.2	51.0	35.3	35.4
680	0.1	6.4	58.5	49.8	47.8
700	—	10.3	61.5	71.1	67.0

The colours given by the above energy distributions are closely similar although not identical, and their coefficients, calculated by numerical integration every 10 mμ, are given in Table 6.

TABLE 6.
Colour match data for typical colours.

Colour Filter	Colour with Illuminant A
M.T. light limit green	0.230X + 0.414Y + 0.356Z
G + S + D	0.232X + 0.413Y + 0.355Z
Gold ruby glass	0.613X + 0.345Y + 0.042Z
R + C + W	0.613X + 0.344Y + 0.043Z
O + C + P	0.616X + 0.346Y + 0.038Z

6. Brightness of the Exhibited Colour Signal

A range of illuminations was required for the measurements to be made on the recognition of the colours given by the colour mixer, and provision was made for this by changing the diameter of the exit aperture.

The intensity level for the observations is expressed in terms of the illumination produced at the observer by the light source and, at a distance of 12 ft., a unit illumination of one sea-mile candle (0.754 mile-candle or 0.271 x 10^{-7} ft.c.) requires the intensity of the source to be 3.9 x 10^{-6} candles.

The brightness of the mixed colour for one primary beam was 0.92 x 10^{-3} candles/cm.^{2}, and thus an exit aperture 0.074 cm. diameter gave one sea-mile candle at 12 ft., subtending 0.7 minutes of arc. The corresponding diameters for 10 and 100 sea-mile candles were 0.234 cm. and 0.74 cm., subtending 2.2 and 7 minutes of arc respectively. The limit of the apparatus was 3,400 sea-mile candles illumination, obtained by employing a 1.07 cm. diameter aperture and placing the observer at a distance of 3 ft., and this represented the largest source for which the colour mixer would give complete mixing and also the largest source which might be assumed to obey the laws relating to a point source.

The figures employed in matching the intensities of the primary colours and in calculating the illumination level for the observations are based on high-brightness photometry in which there was no Purkinje effect. This is a necessary precaution in obtaining accuracy, and gives results comparable with those which might be obtained, for instance, in the measurement of filter glasses used for coloured light signals, but in addition it was found that foveal observation gave no significant Purkinje effect.

PART II.—MEASUREMENTS ON THE RECOGNITION OF SIGNAL COLOURS.

7. The Problem.

There is an immediate practical interest in an investigation into the association of certain names with certain ranges of colour, which extends beyond the more obvious academic interest, and the experiments to be described have been directed towards a solution of the practical problem. With the development of coloured signal lights in connection with aviation, marine, railway and road traffic, a system of specification has been generally adopted which defines on the C.I.E.(7) colour chart areas or loci within or along which such colours must lie. The essential principle underlying all such specifications has been that they should crystallise the existing knowledge and experience of working conditions, and different standardising bodies have chosen somewhat different specifications according to the demonstrations made to them of certain satisfactory or unsatisfactory colour filters and according to the previous practice of their country or industry.

In recent years attempts have been made to reach consistency between different opinions and requirements by exact and comprehensive investigation. Van der Werfhorst(8) and Dimmick(9) have investigated the distribution of colour nomenclature along the spectrum, and McNicholas(10) has investigated the nomenclature of a series of coloured glass filters. A report on the recognition of coloured lights has been prepared by Hill(11) and circulated confidentially to the British Aviation Lighting Committee. This report covers the same ground as the present paper and, as the drawing of the master diagrams from which the figures in the present paper are copied had been completed before it was circulated, the author has refrained from reading it so that the two sets of results may be entirely distinct. It is understood that an extension of McNicholas' work is being undertaken at present by F. C. Breckenridge and a third set of results should soon become available. Many experiments have also been made in isolated regions of the colour chart, of which typical examples are Guild's(12) work on yellow for railway signals,

and the work done for the American Railroad Association by Gibson and others[13].

The present work constitutes an attempt to obtain information regarding the recognition of the simple colours used in signalling systems, under varying conditions of observation. The approach to such a problem must essentially be statistical. The information may be obtained by field experiments, as by McNicholas and by Gibson, or by laboratory experiments as by Van der Werfhorst and by Hill. The latter method has been adopted for the present work, in view of its great advantages of accurate control and analysis.

It must be emphasised that laboratory results require to be correlated with the full-scale conditions of any particular requirement in order to apply them to best effect. Examples of the large variations which occur in the setting-up of standards by full-scale observations have been collected elsewhere[14] by the author, and the ultimate choice of limits in a colour specification must depend on the correlation of the laboratory experiments at all points over the colour chart with the full-scale experiments on isolated colours under practical conditions. When these limits are eventually chosen they must be defined in terms of the colorimetric properties, measured in the laboratory, of glasses and light sources which are satisfactory in practice.

8. The Experimental Method.

(1) Scope of Investigation.

Observers were shown the series of 256 colours provided by the colour mixing apparatus already described, and were asked to give one of a small choice of colour names to each colour in turn. The probability of each name occurring was deduced, and thus the regions of the colour chart which are most likely to receive a particular name may be shown by diagrammatic representation using contours of frequency of occurrence of the name.

Six observers were chosen, and each made a large number of observations. The method of choice is described in Section II. below, and it was endeavoured to obtain observers who were representative of the majority. The observations covered an area of the colour chart which encloses all possible colours in general signalling use except the extreme dichromatic violet glasses, with illumination levels from one sea-mile candle to 3,400 sea-mile candles and with several possible choices of colour names.

(2) Operation of the Apparatus.

It has already been described how the colours are obtained by inserting test stencils in the path of the light beams in the colour mixer. Each test stencil was marked with a reference number, with the proportions of the primaries which it selected and with the C.I.E. coefficients of the combined colour which it gave. As the stencils were being used in one run, they were being shuffled for the next run, by placing them at random on four piles which were afterwards combined. The object of shuffling the stencils was first to avoid consistent irregularities such as might occur if a pale yellow-green were always shown immediately after several reds when it might be expected to receive an undue proportion of the name "green." Shuffling also nullified any gradual changes during the run, such as tiredness, increased adaptation, voltage change or development of a more or a less severe criterion of colour naming by the observer.

The observer sat comfortably in an armchair in a completely dark room, free to move his head or to change his position, provided he did not lean forward or move too far sideways. If he usually wore spectacles he kept them on. He was given at least five minutes for dark adaptation, and although the parafoveal threshold goes on decreasing for much longer, with a light which is showing for more than a second and when foveal vision must be used to recognise colour to best advantage, a period of five minutes was enough. There was appreciable dazzle at 100 sea-mile candles.

Each observer was briefly instructed regarding the object of the experiment and the choice of colour names, with one or two trial colours exhibited during the dark adaptation period.

The colour mixer was behind a light-tight partition, and the combined colour could be seen through a small aperture. It was exhibited as an intermittent signal with a 2-second period (1 sec. bright and 1 sec. dark), and the observer allowed as much time as he liked to identify it. It was generally identified on the second flash, and, as the stencils required about 4 seconds to be changed, a complete run of 256 colours occupied about forty-five minutes. A slower run was tiring to the observer.

As the operator put a stencil into position, he gave its number to his assistant and uncovered the exit aperture of the colour mixer. The observer would then give the colour name, which was recorded by the assistant on a printed form, and the exit aperture was covered while the stencils were being changed. There was no record of the order in which the colours were exhibited to the observer.

(3) Analysis of Results

When all the observations were completed in a series, a table was prepared showing the number of occasions that each of the permitted names was given to each test colour. These were reduced to percentages and written against the corresponding points on a large scale chart, such as Fig. 2, so that contours could be drawn to represent the frequencies of occurrence of each name under the conditions employed for the series. In drawing these contours, local divergences for individual colours were disregarded if the amount of the divergence was less than the statistical probable error. Fig. 17 is typical of the contours which were drawn, although the remainder of the diagrams contain only a few contours in the interests of simplicity. Every effort was made to avoid preconceived ideas as to where the contours should lie, and each diagram has been drawn on its own merits without cross reference from one set of conditions to another. There is, there-

fore, little likelihood of real differences having been eliminated in mistake for experimental variations.

Comparisons are drawn between different sets of conditions of illumination level, colour choice, etc., in section 14 below.

9. Colour Nomenclature

In statistical inquiries of this character the numerical values obtained depend to a considerable extent on the exact form of the questions asked and the kinds of answer to which the observer is confined. For instance, an observer presented with a very bluish-green and asked to call it either "green" or "not green" would almost certainly call it "not green," but asked to call it either "green" or "red" would certainly say "green." The limits of the area called green when the choice is "green" or "not green" would be different from those when the choice is "green" or "red." As a general study of visual discrimination and classification it would be of interest to make a series of tests in which the observer gave any name he liked to the test colours, but from the point of view of signal work the significant results will be those in which the observer must make one or other of the decisions which he is called on to make in practice.

There are two types of practical problem; the first is to name a colour which the observer knows to be one of two or three alternatives, such as in marine signalling, when all lights are red or green or white, and the second is to name a colour which may be anything. The practical decision in the first problem may be reached by rejecting the other alternatives, whereas the decision in the second problem requires positive recognition of the colour.

The choice of names which is allowed to the observer must be restricted in order to simulate the decisions made in practice and to facilitate analysis of the results, but must not be so restricted that no name at all can be given to some of the test colours. For instance, an oil flame (1900°K) was generally called "yellow," although when the choice was restricted to red, green or white the observer chose "white" without difficulty. When the choice was restricted to red or green, however, the observer was unable to choose either.

For the present work the following simple names only were allowed:

Red	...	(R)
Yellow	...	(Y)
Green	...	(G)
Blue	...	(B)
Purple	...	(P)
White	...	(W)
Neither	...	(N) used in Series IV. only.

For certain conditions two or more of these names were cut out.

The name purple involves a peculiar difficulty in that a purple point source is unrecognisable as such except by the effect of chromatic aberration, and inexperienced observers have very different ideas as to the meaning of purple, violet and crimson.

The name "neither" was used only in Series IV.,

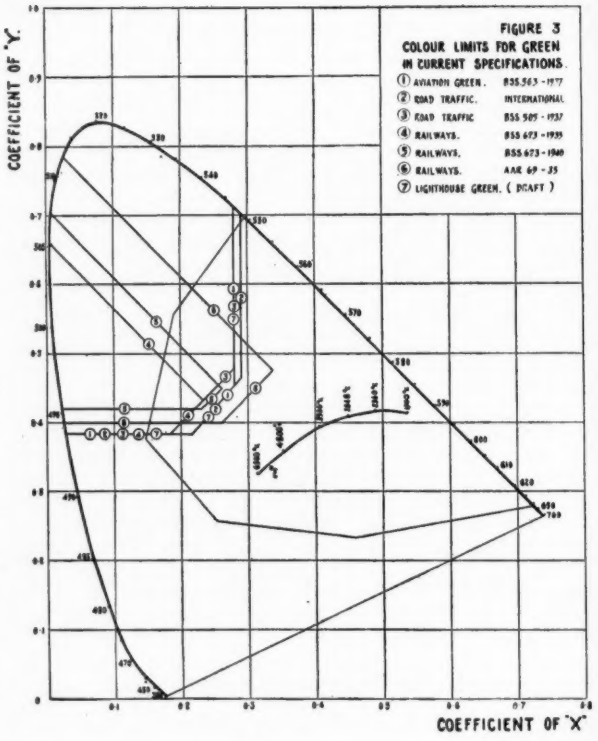
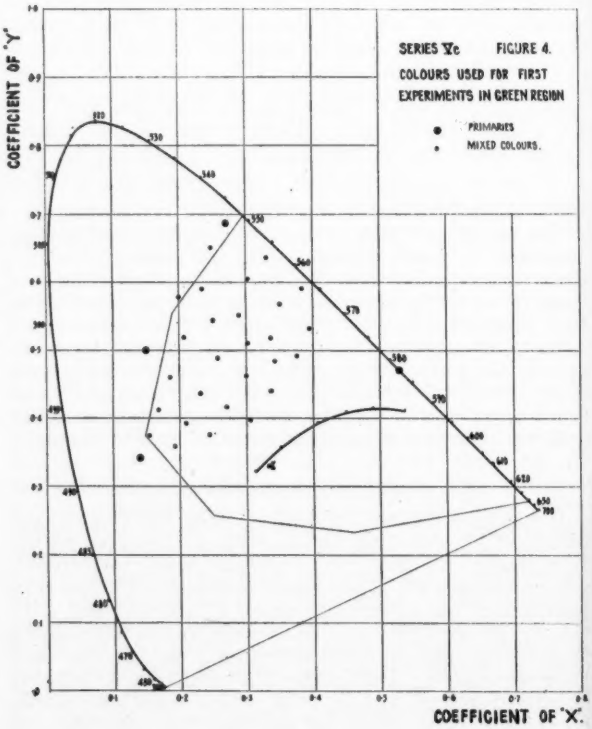


FIGURE 3
COLOUR LIMITS FOR GREEN IN CURRENT SPECIFICATIONS.
① AVIATION GREEN. B.S.S.613 - 1947
② ROAD TRAFFIC. INTERNATIONAL
③ ROAD TRAFFIC B.S.S.505 - 1937
④ RAILWAYS. B.S.S.673 - 1939
⑤ RAILWAYS. B.S.S.673 - 1940
⑥ RAILWAYS. A.A.R. 69 - 35
⑦ LIGHTHOUSE GREEN. (DRAFT)
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'



where the choice was red, yellow, green or neither. It was suggested to the observer that the light would be one of the first three colours, but if he could not say which he was to use the name "neither."

10. Summary of Preliminary Experiments

The first part of these experiments was confined to the green area of the colour chart, where there is a great divergence between different specifications as shown in Fig. 3, with a view to obtaining a basis for choosing a light limit for lighthouse purposes (14). These early experiments were not entirely satisfactory owing to their restricted scope, but it is interesting to summarise some of the facts which emerged from them. The area of the colour chart covered in these experiments is shown in Fig. 4.

(1) Experiments on Nomenclature

The first experiments had to be completed at short notice, and a short cut was used at first to collect and interpret the results of a small number (15) of observers. Each observer was asked to give one of the names in Table 7 to each colour:

TABLE 7.

Choice of name in first experiment.

Colour Name	Significance	Weight
Green	Undoubtedly green	10
Green-blue	Meaning green predominant with a tendency towards the second colour name.	10
Green-yellow		6
Green-white		5
Blue-green	Meaning the first colour name predominant with a tendency towards green.	6
Yellow-green		4
White-green		3
Blue-yellow	Meaning the first colour name predominant with a tendency towards the second colour name.	3
Blue-white		3
Yellow-blue		3
White-blue		1
Yellow-white		0
White-yellow		0
Yellow	Undoubtedly Yellow	0
White	Undoubtedly white	0

The "greenness" of the name given by each observer was weighted in accordance with an arbitrary system, the weights being chosen beforehand, as shown in the right-hand column above. It was endeavoured to weight them in such a way that, for instance, a colour called "white-green" would, if the observers had been restricted to the simple names "green" and "white," have been called "white" by 70 per cent. and "green" by 30 per cent. of the observers. This was entirely an emergency measure, but it so happened that the mean results were substantially correct.

In making this first series of measurements, it was immediately obvious that the observers could be definitely divided into two groups giving significantly different results. One group comprised those experienced in photometry or in lighthouse signalling practice, and the other group comprised those without any previous experience of reading or assessing light signals. The difference was that the inexperienced group were slower in choosing the colour name, gave indefinite names over a wider area of the colour chart, and gave the name "green" on only 70 per cent. of the occasions when it was recorded by the experienced group. This rendered the results suspect, and further experiments were made.

The second series of measurements was made with the same observers and with the choice "green" or "not green." The difference between two groups disappeared, and the loci of 90 per cent. and 50 per cent. occurrence of the name green was found to agree closely with those plotted from the weighted names in the first series. This simple choice gave a more rational meaning to the results and also a smaller scatter was obtained.

A set of 18 observations on the 30 colours by one observer showed that a fair appraisal of doubtful colours could be made by allowing him to give three names together to each colour exhibited, such as "green-green white," if he thought that on three separate observations of the colour he would call it "green" twice and "white" once. The 90 per cent. and 50 per cent. loci plotted from these observations did not differ appreciably from those plotted from the "green" or "not green" choice by 15 observers and the scatter was appreciably less. At the same time, it appeared that the colour names weighted 6 or more in the first series were generally called "green" and those weighted 5 or less were generally called "not green."

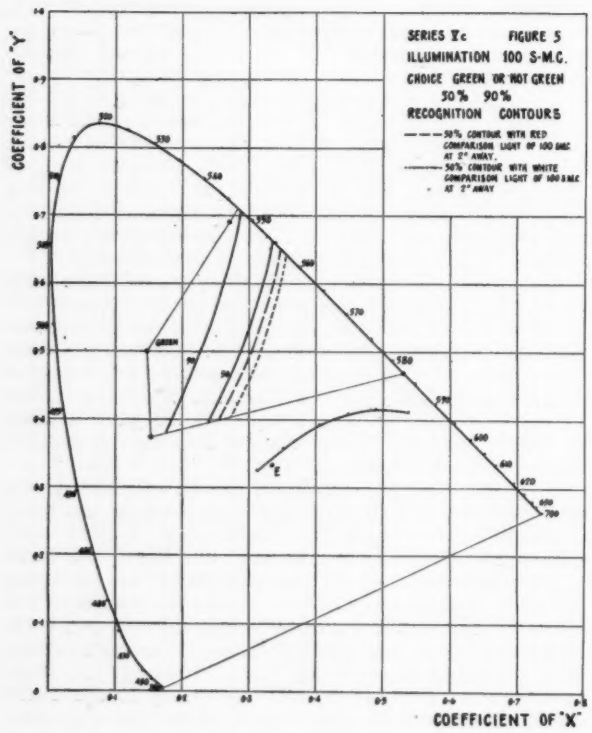
On the basis of these experiments it was decided that the main work must be done by the observer giving one name only to each colour, and that this name should be one of a restricted list. It would be possible to give the selected observers simple training in the combination of three names as above for subsidiary experiments, provided the operator checked the observer to ensure that this short cut was not abused, and in practice it was found later that the triple naming was used on 16 per cent. of the test colours in Series II, III and IV only. This combination of names was not to be used by the larger number of observers from whom the selected observers were to be chosen.

(2) Results of Preliminary Experiment.

The results in the green area are based on the choice "green" or "not green" and are shown diagrammatically. In Fig. 5 loci are given representing the colours which are called "green" on 90 per cent. and 50 per cent. of occasions. A variety of conditions were employed in this preliminary experiment, about which it is sufficient to give the general conclusions.

(2a) Effect of Illumination Level.

Several sets of observations by one observer at 1.0, 1.5, 4, 5 and 100 mile-candles showed no significant difference above 4 mile-candles, and a greater tend-



ency to call colours "not green" below 1.5 mile-candles.

(2b) Effect of Comparison Light.

A colour was more likely to be called green if a known comparison light was in the vicinity. This effect is shown in Fig. 5. A white comparison light was more effective than red.

(2c) Order of Observation.

One or two anomalous cases arose in which a colour outside the 50 per cent locus was consistently called "green." In each case it was found that the preceding colours were considerably less green and, as a constant rotation was employed, observers tended to give an inconsistent name regularly. This effect was partially eliminated by changing the order and could be completely eliminated by shuffling the order from one observer to the next.

(2d) Absence of Other Colours.

A criticism of this experiment in a restricted area of the colour chart was the undue importance given to the name "green." Some colours exhibited were invariably called "not green" and were deliberately included in order to give the observer a chance of seeing something other than green lights, but even so he was generally unduly critical as to the border line between green and not green. All the observers thought that a comparison white light exhibited on some occasions alongside the test light was yellow, although it was between 2600°K and 2800°K, and about half the observers called 580 mμ "orange" when asked. For these reasons the results of this experiment are not considered to be of any great value, and are to be expected to represent a more severe criterion of recognition of green than would be found in practice.

(2e) Choice of Colour Names.

The results emphasised the value of a simple choice from a small number of names and, after a little experience, an observer could make quantitative estimates of his reaction to doubtful colours.

The results of this preliminary experiment were reported to the International Lighthouse Conference at Berlin in 1937 ([15]), and they proved sufficiently promising to justify the more complete experiments.

11. Analysis and Selection of Observers.

The full range of the experiments was made with six observers who were chosen from fifty of Chance Brothers' staff and workpeople with normal colour-vision and representing a cross-section of the population. Each of the fifty observers was shown the run of 256 colours at 10 s-m.c. illumination and asked to give to each colour one of the names red, yellow, green, blue, purple and white. The characteristics of these fifty observers are set out in the Appendix in the order of increasing departure from the average. It will be seen that experienced and inexperienced observers were used, their ages varying from 18 to 63, with an average of 35, and that six women were included.

It is interesting that the six women are high in the list and the men whose lifetime has been spent in matching coloured glasses are low in the list. The correlation between age of observer and order in the list is 0.47, which is not high, but indicates better discrimination for the younger observers. No correlation was found between an arbitrary order in which the author put the observers from personal knowledge of their experience and the order in the list.

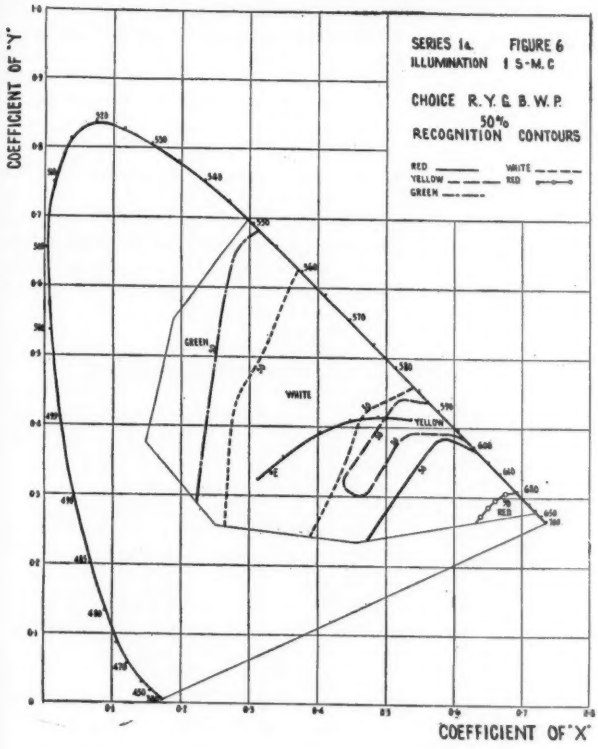
The criterion for the choice of the six observers was that they should give the same name to each test colour as the majority of the fifty observers on the largest number of occasions. Observer No. 1, nearest to this requirement, differed from the majority on only twenty-two colours, and the majority vote of the six selected observers was the same as the majority vote of the fifty for 247 colours out of the 256.

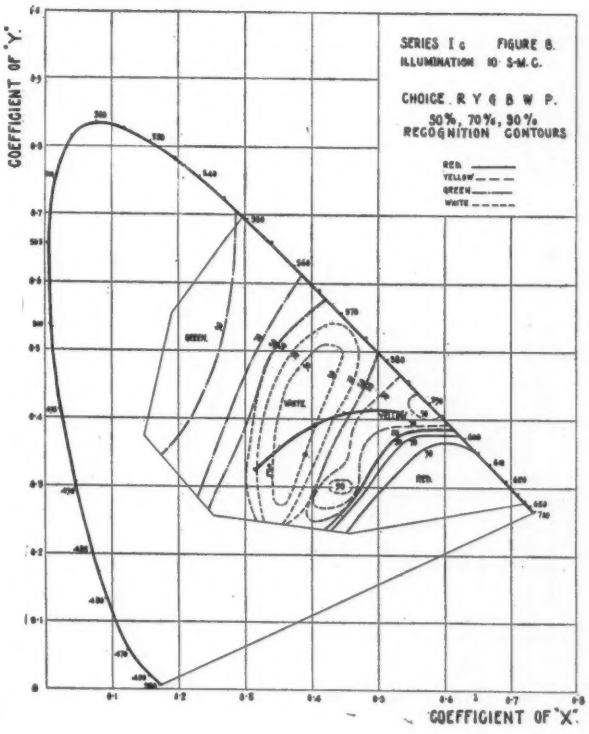
The method of setting the fifty observers in order is described in the Appendix and the selected six who were able to give the time are marked with an asterisk in the table. All were male, between twenty-two and forty-two years of age, and possessed varying degrees of experience in colour observation.

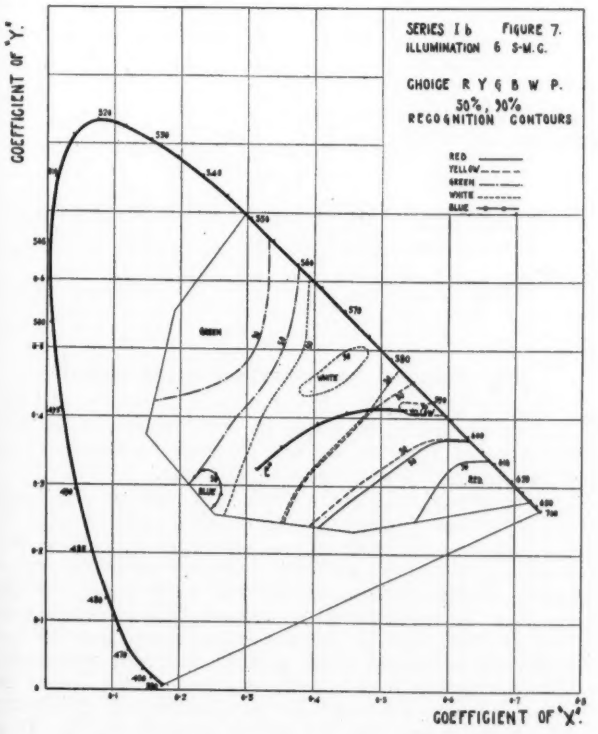
12. Programme of Investigation.

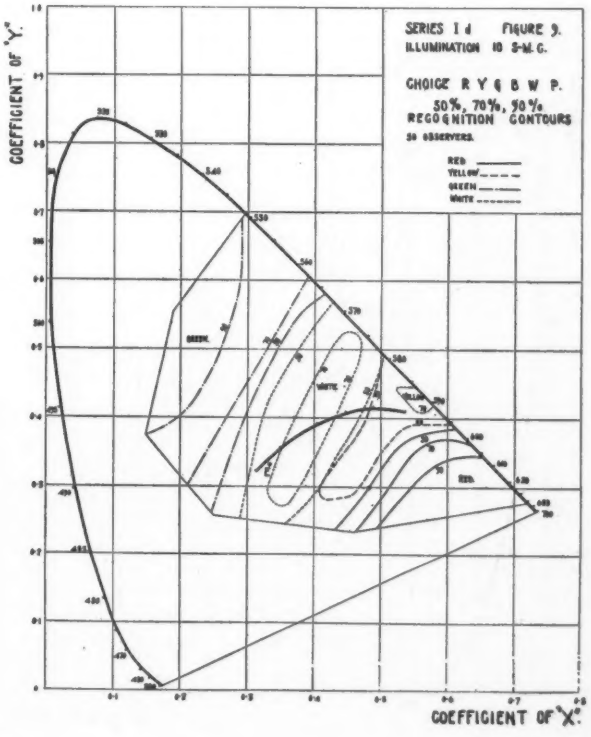
Five series of observations have been made using different choices of colour names, and in Series I several illumination levels. 43,504 individual observations have been made and are filed for reference and further analysis if necessary.

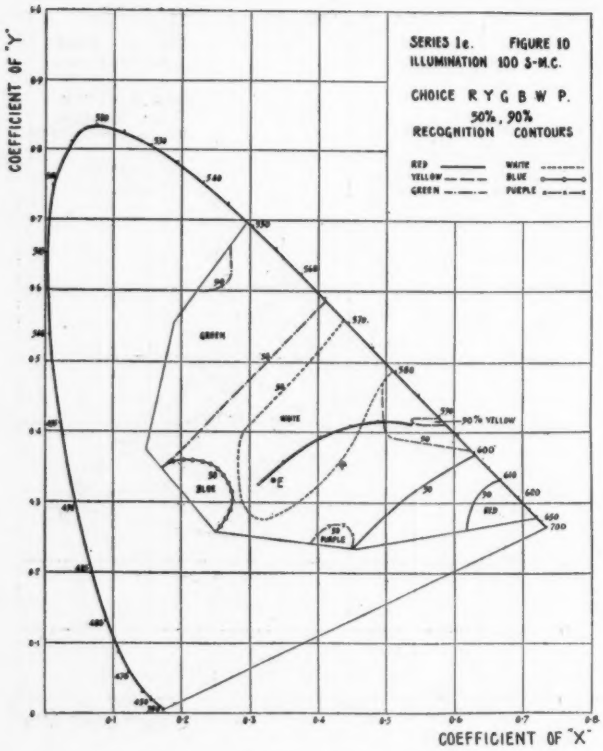
The results are expressed as diagrams of the C.I.E. colour chart on which contours have been drawn to

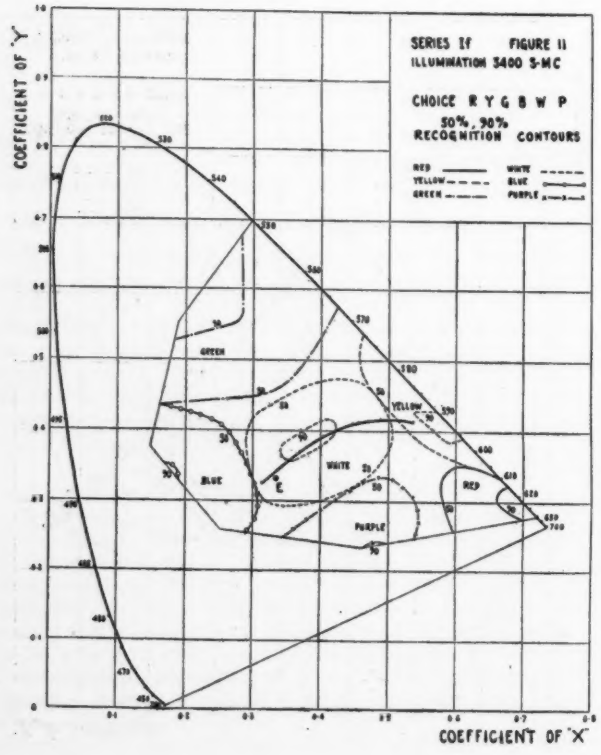

SERIES Ia. FIGURE 6
ILLUMINATION 1 S-M.C
CHOICE R.Y.G.B.W.P.
50%
RECOGNITION CONTOURS
RED
YELLOW
GREEN
WHITE
RED
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'


SERIES I c FIGURE 8.
ILLUMINATION 10 S-M.C.
CHOICE R Y G B W P.
50%, 70%, 90%
RECOGNITION CONTOURS
RED
YELLOW
GREEN
WHITE
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'


SERIES I b FIGURE 7.
ILLUMINATION 6 S-M.C.
CHOICE R Y G B W P.
50%, 90%
RECOGNITION CONTOURS
RED
YELLOW
GREEN
WHITE
BLUE
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'


SERIES I d FIGURE 9.
ILLUMINATION 10 S-M.C.
CHOICE R Y G B W P.
50%, 70%, 90%
RECOGNITION CONTOURS
30 OBSERVERS.
RED
YELLOW
GREEN
WHITE
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'





show the frequency of occurrence of the different colour names. Each diagram has the spectrum locus with a wavelength scale in mμ, the equi-energy white point E and the Planckian white locus from 1900°K to 6500°K, the intermediate temperatures being 2360°K, 2848°K, 3500°K and 4800°K, as in Fig. 3. The limits of the area covered by the 11-primary mixer are also shown to make it clear which colours have been investigated.

A single diagram on the R.U.C.S. basis ([16, 17]) has been given to illustrate in some degree the subjective differences between the various colours investigated.

Table 8 sets out the different series of observations:

TABLE 8.

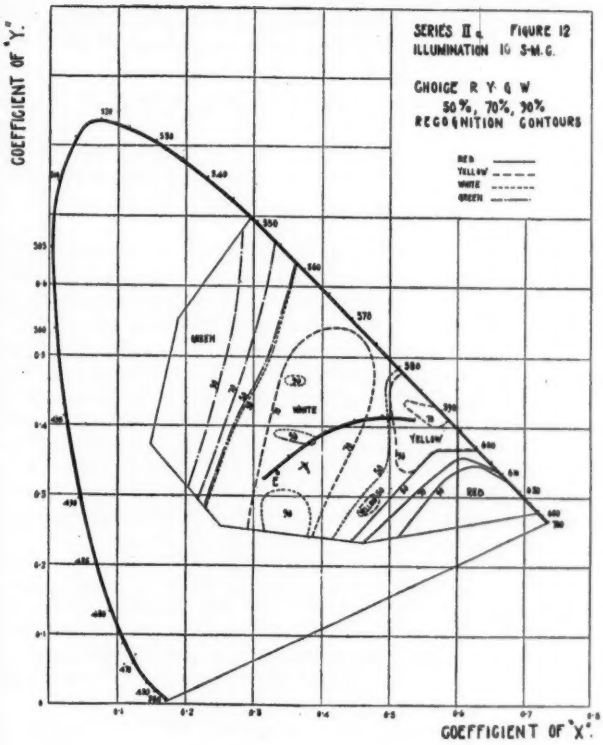
Programme of experimental conditions.

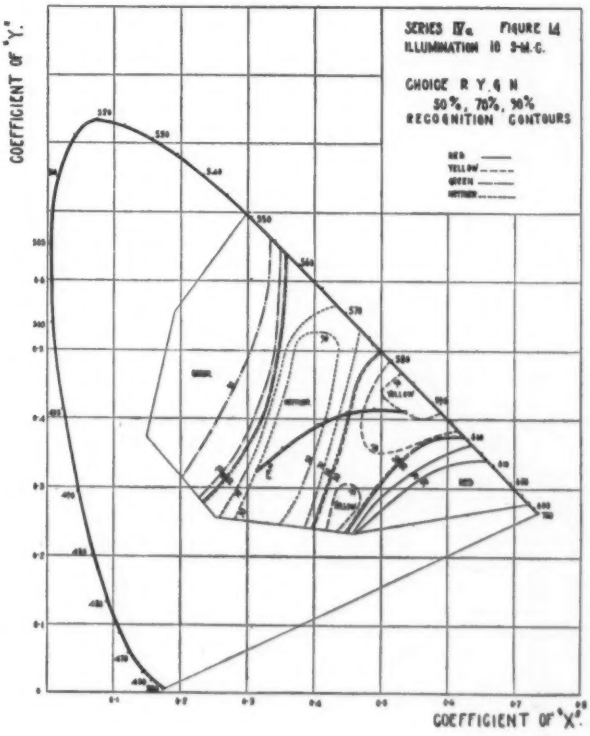
Series	Permitted colour-names	Illumination level (s-m-c.)	Diagram No.	No. of observers	No. of Obsns.	Remarks
Ia	Red	1	6	6	4,608	
b	Yellow	6	7	13	3,328	
c	Green	10	8	6	1,536	
d	Blue	10	9, 17	50	12,800	
e	Purple	100	10	6	4,608	
f	White	3,400	11	4	3,072	
IIa	Red, Yellow, Green, White	10	12	5	3,840	
IIIa	Red, Green, White	10	13	5	3,840	
IVa	Red, Yellow, Green, Neither	10	14	5	3,840	
Va	RYGBPW	10	15, 16	4	3,072	Desk light
b	RYGBPW	10	—	3	408	Diverging lens
c	G or Not G	100	5	3	540	4-primary mixer

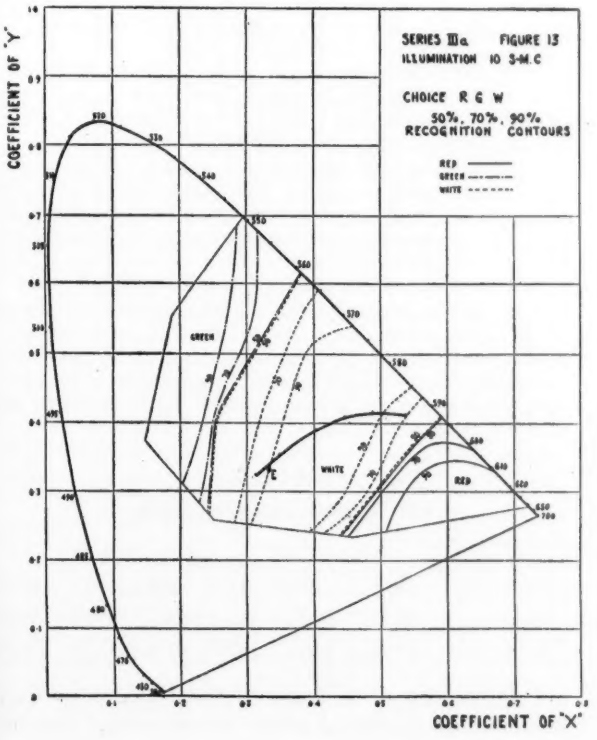
13. General Consideration of the Results.

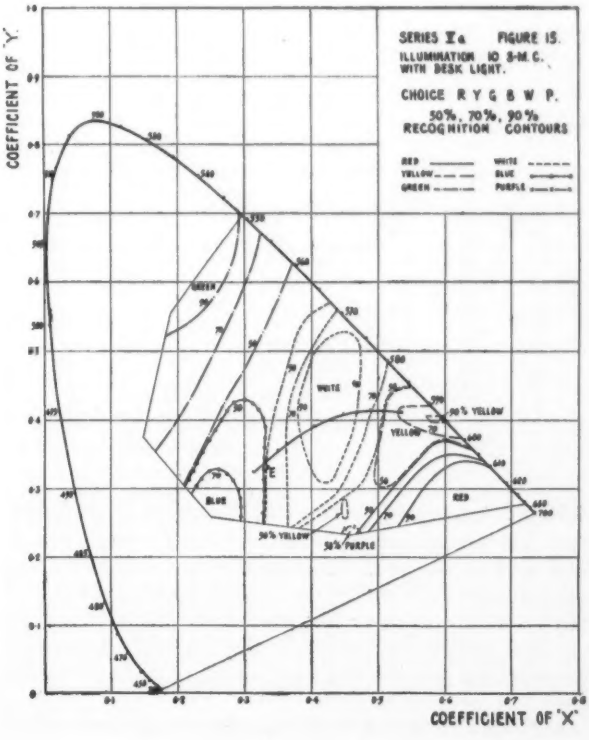
The diagrams are almost self-explanatory, but the labour of studying them is considerable and may perhaps be reduced by the descriptive summary in this and the two succeeding sections.

Any given contour on the diagram is the locus along which a given colour name occurs at a given frequency. Taking as an example the 80% red contour, we may say that it represents 80% occurrence of the name red or that each point on the contour is recognised as red on 80% of occasions. The contour will be the same in either case but the different points of view give it different meanings. The discussion that follows is based on the latter interpretation, although it postulates an arbitrary "correct" name for the colour at each point. It is


SERIES IIa FIGURE 12
ILLUMINATION 10 S-M.C.
CHOICE R Y G W
50%, 70%, 90%
RECOGNITION CONTOURS
RED
YELLOW
WHITE
GREEN
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'


SERIES IVa FIGURE 14
ILLUMINATION 10 S-M.C.
CHOICE R Y G N
50%, 70%, 90%
RECOGNITION CONTOURS
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'


SERIES IIIa FIGURE 13
ILLUMINATION 10 S-M.C
CHOICE R G W
50%, 70%, 90%
RECOGNITION CONTOURS
RED
GREEN
WHITE
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'


SERIES Va FIGURE 15
ILLUMINATION 10 S-M.C.
WITH DESK LIGHT.
CHOICE R Y G B W P.
50%, 70%, 90%
RECOGNITION CONTOURS
RED
YELLOW
GREEN
WHITE
BLUE
PURPLE
50% YELLOW
50% PURPLE
COEFFICIENT OF 'Y'
COEFFICIENT OF 'X'

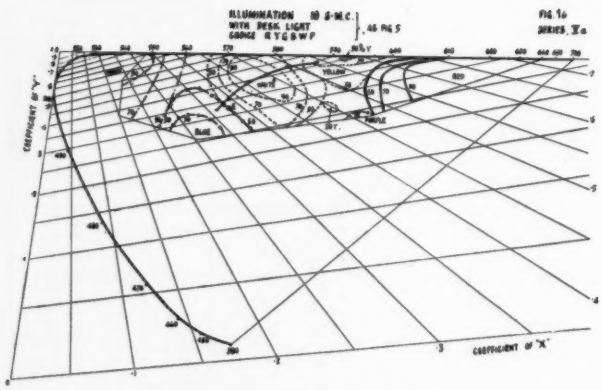
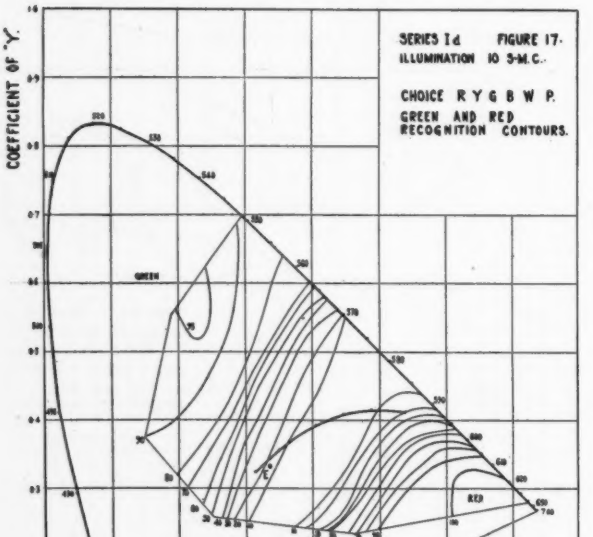


Fig. 16. Recognition of Contours (Series Va) on R.U.C.S. diagram.



difficult to say of a scarlet colour on this locus that it is recognised as yellow on 20% of occasions and it would be easier to separate the low and high frequencies by saying that the colour was recognised as red on 80% occasions and the name yellow occurred on 20% occasions. Most of the contours represent frequencies greater than 50% and so this difficulty does not become serious.

In Series I and II a doubtful colour was often called white even though on second thoughts it was quite obviously not. This was most prevalent at low illuminations and resulted in a wide scatter of low occurrence of the name white. The choice Red, Yellow or Green proved impossible because of the large number of white and doubtful colours which could not be given any of these names, although observers had little difficulty with the choice Red, Green or White in Series III.

For this reason, high recognitions do not appear at low illuminations except for red and there is a general scatter which prevents the 50% recognition contours from coinciding between two colour regions.

At high illuminations, the areas have more definite boundaries, owing to improved discrimination which brings the contours of any one colour name closer to each other.

It will be seen from most of the diagrams that the whole area of the colour chart is divided into fairly well-defined regions in which the simple colour names predominate and the colours in these regions are recognised on a high proportion of occasions. The change-over from one region to the next is not necessarily associated with a small hue- or saturation-limen, but is connected with the observer's inbred tendency to recognise the simple colours. The tolerances allowed in signalling colours are dependent on the position and extent of these regions of high recognition.

To a very rough approximation, the boundaries of the high recognition areas meet the spectrum locus in a radial direction from white. Thus the red region terminates in a line of constant Y-coefficient, the yellow region has boundaries perpendicular to the spectrum locus on the C.I.E. chart and the boundary of the green region, on the yellow side, is a line of constant X-coefficient. The green-blue boundary is not determined by these experiments.

A safe signalling colour is one which can be recognised with confidence at a large distance or at a low illumination and with certainty at a high illumination. The boundary between low and high is the important variable which produces differences in the colour tolerances allowable for different purposes.

A simple example of the correlation which can be made between these results and the full-scale requirements is afforded by railway signalling practice. For many years only red, green, and white were used, and the colours of these signals lay between the limits given in Table 9.

TABLE 9.

Old Railway signalling limits.

Railway Signal Colour	Light limit	Dark limit
Red	.680X+.315Y+.005Z	.700X+.300Y+.000Z
Green	.285X+.490Y+.225Z	.220X+.495Y+.285Z
White	.515X+.415Y+.070Z	.540X+.415Y+.045Z

The intensity of an average signal would be about five candles, giving 6.5 s-m.c. at one mile. The cor-

responding recognition figures at 10 s-m.c. for the RGW choice are given in Table 10.

TABLE 10.
Recognition of old railway limits.

Colour	Light limit	Dark limit
Red	92%	100%
Green	70%	98%
White	85%	72%

Needless to say, these colours were entirely safe for their particular purpose.

It may be noted that the choice of the limits which are required to ensure that a colour is safe for its purpose must rest on a compromise between high recognition and low light transmission of the filter glasses. This compromise is examined in detail in Section 16.

It is convenient here to discuss the effect of using selected observers and to compare their results with those of the larger number. The average of the results of the six observers is given in Fig. 8 and that of the fifty is given in Fig. 9, and the similarity between these diagrams bears out the assumption that the same result would be given by a small number of "average" observers making several observations as by a larger number of observers, with less scatter in the distribution of colour names.

The six observers, being chosen to give the least scatter, must necessarily give larger areas of high recognition, but should give the same contours for 50% recognition and also the same dominant name to each test colour as those given by the fifty observers. Regarding the areas of high recognition, the six observers gave over 90% recognition to 113 test colours, whereas the fifty gave this to only fifty-seven test colours. The corresponding figures for 75% recognition were 192 and 132 respectively. Figs. 8 and 9 show close similarity between the 50% recognition contours, although Fig. 8 is subject to slight uncertainty owing to the smaller number of observations in Series Ic and the comparative lack of colours which were given a name on about 50% occasions.

As regards the dominant name, i.e., the name given by majority vote, there were only nine test colours for which the six observers differed from the fifty. Eight of these were less than 60% recognition, and in seven of them the name "purple" was used by some of the fifty. This name was found liable to indefinite use, and thus it may be stated that the six selected observers agree closely with the larger number for all those test colours which are more clearly recognised.

As just indicated, however, there is a difference in the use of the names "purple" and "blue," which were found not to be consistently recognised as signal colours. The six observers used these names less than the fifty, which may occur for the reduced scatter in their results. The total occurrence of the name "blue" was 3.7% for the six and 6.7% for the fifty, and that of the name "purple" was 0.3% and 3.8% respectively The effect of this difference in reducing the scatter of low-recognition colour names is to make the high-recognition contours in Series Id (Fig. 9 and Fig. 17) somewhat inconsistent with those in the other Series, and it must therefore be stated that the results are for six observers of average discriminating power and are not based on the larger number of fifty.

14. Results of Observations.

The diagrams giving the results are drawn according to the conditions of observation, and each shows all the colour regions. The brief description which follows is set out under the colour names and covers all the sets of observations for each particular colour.

(1) Blue Region and the Purkinje Effect.

One outstanding result of the experiments is that blue is not seen at low intensity. The Purkinje effect of increased visibility of blue applies only to extra-foveal rod vision in which there is little or no colour sensation, and it has been shown ([18]) that the fovea is subject to a reverse effect. There are two possible explanations of this phenomenon, the one being that the cones in the fovea do not possess the greater sensitivity to blue possessed by the rods, which would account for the absence of a positive Purkinje effect, and the other being that the chromatic aberration of the crystalline lens is such that the eye is focussed on the longer wavelengths and blue rays are not focussed sharply. The retinal illumination by blue rays from a small light source is thus reduced and leads to a reversed Purkinje effect. Experiments with a −1D lens over each eye were made, and a significant increase in the recognition of blue was found. The results are given in Section 14 (7a) below.

The blue primary was a rich blue colour, being a cobalt glass of 5.75% transmission, and was undeniably blue when observed from a short distance. Table 11 gives the percentage occurrence of names in Series I.

TABLE 11.
Names given to the blue primary.

Illumination	Percentage occurrence of names:		
	Blue	White	Green
3,400 s-m.c.	67	28	—
100	54	28	4
10	39	7	51
6	36	15	49
1	17	54	29

The comparative lack of blue contours on the diagrams is also due to the blue region of the colour chart not being well covered by the primaries used in this experiment, which was chiefly concerned with glasses suitable for signalling purposes. Blue glasses require to be of very low transmission in order to give colours of high purity, and as this experiment was restricted to glasses of about 5% transmission with 2360°K, no pure blue colours were used. There was therefore an ample proportion of rays of longer wavelength on which the eye could focus and which would tend to mask the blue rays when observing a point source.

It is interesting that at low illuminations the name

"blue" was scattered over the whole chart and that all the names except red occurred in the blue region.

(2) The Purple Region.

This is subject to much the same considerations as the blue region. A considerable number of purple test colours were exhibited, but at low illuminations the predominant name of the more saturated purples was "red." The bluer shades of purple are recognisable as a dichromatic signal, due to chromatic aberration producing the effect of a red spot with a blue halo (myopic observer), a blue spot with a red halo (hypermetropic observer), or a cross of which one arm is red and the other blue (astigmatic observer). This type of signal calls for high brightness and is not one with which this paper would attempt to deal. Glasses of this type are used on American railways with a high intensity lens system and have a transmission factor of about 1%.

Colours between the purple primary and the white point tended to be called yellow and the island areas of yellow as in Figs. 12 and 14 were significant in the observations recorded.

The general scatter which appeared with the name "blue" at low illuminations did not appear with the name "purple," but on the other hand all the other names occurred occasionally in the purple region. The increased recognition of blue and of purple at high illuminations affects the adjoining boundaries and it will be seen that the red and green boundaries are moved back and the white boundary is moved up for this reason.

These measurements on blues and purples emphasise the importance of matching the energy distributions in the combined colour and in the signal glass filter which it represents, and it may well be that different results would have been obtained with the same observers and colour mixer if the purple primary had had a different spectral composition.

(3) The Red Region.

The results in the red region are simple, and so the effect of different conditions may be usefully discussed. The occurrence of the name "red" is very high for some of the test colours, as might be expected from the generally satisfactory nature of red signals.

Considering the different results in Series I., it will be seen that increasing the illumination level from 1 s-m.c. to 100 s-m.c. increases the area of high recognition. This is generally true of all the simple colours, as the higher illumination permits better discrimination with less scatter in the observations and more definition to the boundaries. Conversely high illuminations are accompanied by a reduction in the area of low occurrence of the name. At 100 s-m.c. however, it is seen that the increase in blue and purple recognition is reducing the proportion of purples which are called red, and the 90% recognition contour at 3400 s-m.c. is moved back very considerably for this reason and also because the name "yellow" appears more frequently. The intercepts on the spectrum locus are given in Table 12.

Considering the intercepts on the spectrum locus,

TABLE 12.

Intercepts on spectrum—red region.

Series	Colour Choice	Illn. s-m.c.	Intercepts on spectrum			% Recognition of 610mμ
			90%	70%	50%	
Ia	RYGPBW	1	620mμ	605mμ	601mμ	80
b		6	608	605	601	93
c		10	604	599	597	95
d		10	606	602	597	93
e		100	610	606	601	90
f		3,400	614	613	610	50
IIa	RYGW	10	615	610	601	70
IIIa	RGW	10	612	602	593	88
IVa	RYGN	10	608	602	599	92
Va	RYGBPW	10	610	607	603	90

it must be acknowledged that the high recognition of red at 10 s-m.c. in Series I. may be due to experimental error, but it appears certain that the full colour choice (RYGBPW) yields a higher occurrence of the name "red" in the orange region than the restricted choices in Series II.—IV. It seemed that an observer who was allowed to use the names "blue" and "purple" had a different idea of subjective red and was more likely to call an orange colour "red" than when there was no suggestion of the blue sensation. In addition to this, the restricted choice of names is associated with a smaller area of high recognition than might be expected, owing to the difficulty presented by some of the test colours.

It is apparent from several of the diagrams that fully saturated colours are not essential and that a very considerably de-saturated colour may be recognised as red at the illuminations employed. At higher illuminations than these, however, the high recognition contours may be assumed to lie closer to the spectrum locus.

(4) The Yellow Region.

A large number of test colours was used in the yellow region for three reasons. Firstly, the spectral hue discrimination is high in this region, secondly the discrimination between yellow and white is a matter of paramount importance, and thirdly specific claims have been made for the colour of the sodium vapour discharge lamp. The test colours were built up from primaries which were close together so that they possessed similar spectral compositions to those given by single glasses.

The centre of the yellow recognition on the spectrum locus lies at 501mμ (± 1.5mμ) when the names red, green and white are also allowed, and at 588mμ(±2mμ) when the name white is not allowed. The distribution of the name yellow along the spectrum locus varies considerably with different conditions. A greater range of wavelengths is called yellow at high illuminations than at low and at 1 s-m.c. there was no colour which had as much as 70% yellow recognition. The intercepts on the spectrum locus are given in Table 13.

The low recognition of 590mμ in Series Id is apparently due to the large scatter amongst the fifty observers. In Series IIa and IVa, the omission of the

TABLE 13.

Intercepts on spectrum—yellow region.

Series	Colour choice	Intercepts on spectrum locus (mμ)			% Recog. of 590 mμ
		90% Recog.	70% Recog.	50% Recog.	
Ia	RYGBPW	—	589	588—597	60
b		590—593	587—599	585—600	90
c		587—593	583—596	578—597	92
d		—	586—591	578—596	75
e		591—592	583—595	580—600	88
f		589—596	578—598	572—610	92
IIa	RYGW	—	588—592	581—600	72
IVa	RYGN	582—592	580—597	578—599	92
Va	RYGBPW	593—595	591—599	586—602	68

blue choice tends to displace the yellow area away from the red.

At low illuminations greater tolerance could be allowed in the saturation than in the hue-wavelength, whereas at the higher illuminations this is reversed. The requirement in the majority of colour specifications that yellows shall be almost fully saturated appears to be unduly strict. It is generally known that the saturation limen is large for yellows at the same wavelength that the hue limen is small ([19, 20]), under normal high illumination conditions.

The lower colour temperatures of white light lie in the 70%—90% recognition area. This holds for dark adapted observers without a comparison light, but even when the observer was given a white desk light (one f.c. at 2500°K) and read a book between observations, the colour of 1900°K was recognised as yellow on about 70% occasions. This is presumably the reason for insisting on high-saturation yellow glasses for use when oil burners are liable to be seen and also why the yellow signalling colour was not generally satisfactory before electric illuminants were more widely used. The yellow colour was said to be unsatisfactory because of confusion with "white," but actually the unsatisfactory colour was the white which was liable to confusion with yellow. The diagrams also show how the redder side of the yellow region is safest([12]) in this respect, as the white recognition contours approach the spectrum locus on the green side of the yellow region.

Table 14 gives the intercepts of the yellow recognition loci on the Planckian locus above 1900°K.

TABLE 14.

Intercepts on Planckian locus—yellow region.

Series	Colour choice	Illumination s-m.c.	Colour Temperatures (°K)		
			90%	70%	50%
Ia	RYGBPW	1	—	—	2,250
b		6	1,950	2,200	2,350
c		10	—	2,450	2,750
d		10	—	—	2,400
e		100	—	2,100	2,300
f		3,400	—	1,900	2,100
IIa	RYGW	10	—	—	2,200
IVa	RYGN	10	1,950	2,300	2,550
Va	RYGBPW	10	—	1,950	2,100

The results on the sodium colour are given in Table 15. The colour was introduced without warning several times during several runs, all at 10 s-m.c., but the test was only made by six observers, the total number of observations being eighty-eight. The figures in brackets refer to light of the same colour combined by the colour mixer.

TABLE 15.

Recognition of sodium light.

Series	Colour choice	Percentage occurrence of names				No of times shown
		Yellow	White	Red	Green	
IIa	RYGW	83 (83)	9 (0)	8 (17)	0 (0)	28
IIIa	RGW	—	73 (57)	25 (43)	2 (0)	28
IVa	RYGN	100 (100)	—	0 (0)	0 (0)	23
Va	RYGBPW	68 (58)	32 (42)	0 (0)	0 (0)	9

The Series V. results were obtained in conjunction with a desk light. In Series II. and III. the total occurrence of the name "yellow" was the same for sodium light as for the same colour corresponding to a yellow glass filter with tungsten light, but sodium light was called "red" less often than the glass, and was called "white" more often. These results are insufficient to be wholly satisfactory, but they indicate that there is no great difference between the two types of coloured light under normal conditions of observation. This possibly means also that the necessity of matching the energy distribution of the combined colours and that of the glass filters used in practice is not so important in this region of the spectrum as it may be in the blue region.

The occurrence of islands of yellow recognition in the purple region has already been noted, and may perhaps be regarded as an unsatisfactory property of the purple test colours. Unfortunately, there is a rather large spacing between the test colours in this particular part of the chart as this phenomenon was not anticipated when designing the colour mixer.

(5) The Green Region.

The green recognition loci are all straight or very slightly curved except where strong recognition of blue affects them. In Series I., the slope changes consistently with illumination, the low illuminations giving almost vertical contours, and the high illuminations approximating to horizontal contours. The change at the blue end appears to be due only to increasing recognition of blue, but that at the yellow end is not easily understood. It is thought that yellowish-green colours are called white at low illuminations and green at high illuminations, implying that an emerald green is more liable to subjective desaturation than a signal green colour (turquoise).

The green recognition is not greatly affected by the colour choice at 10 s-m.c., in Series I., II., or III., except at the blue end, but Series IV., in which white was not allowed, gave a greater area recognised as green. The white desk light in Series V. reduced the green area to give a larger white area, but the experiments with a comparison white light on the 4-primary mixer showed an increased green area.

The intercepts of the green recognition contours on

the yellow-green region of the spectrum locus are given in Table 16.

TABLE 16.

Intercepts on spectrum—green region.

Series	Colour choice	Illumination s-m.c.	Hue wavelength (mμ)		
			90%	70%	50%
Ia	RYGBPW	1	—	—	551
b		6	554	558	560
c		10	548	562	566
d		10	548	562	566
e		100	(545)	557	565
f		3,400	(547)	556	567
IIa	RYGW	10	(547)	554	558
IIIa	RGW	10	(547)	552	561
IVa	RYGN	10	554	556	557
Va	RYGBP	10	548	553	560
c	G or Not G	100	548	552	555

It is worth recording that endeavours could not be carried through to obtain a check on the theory that certain energy distributions show less tendency to fade towards white at low illuminations than others giving the same subjective colour. It was hoped that combinations of different primaries would produce the types required for experiments in the green region. It was found, however, that even the most diverse combinations, such as B+E and S+Y gave energy distributions which were not seriously different when the combined colours were the same and that this colour mixer is not well adapted to the production of abnormal energy distributions.

(6) The White Region.

The name white is liable to be given to any colours which are difficult to recognise, as has already been discussed, and is therefore somewhat confused with the name "neither" used in Series IV. The results shown in the diagram cover the positive recognition of white test colours and also the use of the name white when the observer thinks the other permitted colour names are not applicable, and these two origins of the name cannot be separated.

The centre of the white region is close to 4000°K, which is comparable with sunlight, and the region extends towards the spectrum locus at 572mμ and towards its complementary. It lies entirely between the yellow region and the green and blue regions, and, in the restricted choices, represents as real a colour as red or yellow. The contours are only closed for the high illuminations, and extend to the spectrum locus at low illuminations.

The whole range of white given by these experiments is not likely to be used, and therefore the intercepts on the Planckian locus given in Table 17 are of special interest.

It is noticeable that the name "white" is given to a larger area in Series III. than the name "neither" in Series IV.

The results with the desk light are significantly different from those for a dark adapted observer.

TABLE 17.

Intercepts on Planckian locus—white region.

Series	Colour choice	Illumination	Intercepts on Planckian Locus (°K)		
			90%	70%	50%
		s-m.c.			
Ia	RYGBPW	1	—	3,400–6,500	2,600–7,000
b		6	—	2,850–6,500	2,400–7,000
c		10	3,500–5,000	3,000–6,000	2,700–7,000
d		10	3,500–5,000	3,000–4,800	2,500–7,000
e		100	—	3,250–5,400	2,600–7,000
f		3,400	3,200–4,800	3,000–5,400	2,250–7,000
IIa	RYGW	10	3,100–5,000	2,500–7,000	1,900–7,000
IIIa	RGW	10	2,200–5,100	1,900–7,000	1,900–7,000
Va	RYGBPW	10	2,600–4,000	2,300–4,500	2,200–5,200

(7) Series Va—Light-adapted Observer.

A test similar to Series I. at 10 s-m.c. was made with the observer reading between observations, the book being illuminated by a shaded light giving 1 f.c. at 2500°K. Only twelve observations were made on each test colour, which renders the 90 per cent. contours difficult to draw correctly, but the results in Figs. 15 and 16 showed sharper discrimination between colours and much higher recognition levels than with the dark-adapted observer in Series I. Fig. 15 is drawn on the C.I.E. colour triangle and Fig. 16 is drawn on the R.U.C.S. colour triangle.

The red recognition was not greatly affected, but all the other colours were affected by a remarkable increase in blue recognition. The blue primary was recognised as blue on 75 per cent. occasions instead of 39 per cent. in Series I., and the green, white and yellow contours were displaced to take account of this and of 50 per cent. recognition of purple. This experiment was the only one in which 6500°K was considered blue, and the difference may be due either to reduced pupil size or to comparison with a yellowish "white light." The intercepts of the various contours on the red-yellow-green spectrum locus were not much affected.

(7a) Series Vb—Observer Wearing Concave Spectacle Lenses.

An experiment to test the theory that lack of recognition of blue was due to the chromatic aberration in the eye was made with three observers, wearing —1D lenses over each eye, at 10 s-m.c. illumination and with the RYGBPW choice as in Series I.

All colours normally called blue received the same name, and in addition 14 other colours were called blue which had before been white (12), green (1), and purple (1).

The other names were also affected, such as 24 previously yellow colours being called white and 18 previously red colours being called purple, whereas the reverse changes occurred in 4 cases only. Both these changes are representative of an increased visibility of blue, and altogether amongst the 101 colours which received different names, 88 were in the direction of increased blue visibility and 13 in the reverse direction. This effect is a significant difference in

the recognition of blue due to the lengthening of the focus of the eye.

(7b) VERY LOW ILLUMINATION.

The accepted limit for safe conspicuity of a white light is 0.5 s-m.c., although the threshold is much lower, and the limit for safe recognition of a colour is presumably considerably higher. A single set of observations was made at 0.3 s-m.c. with RYGBPW colour choice. There was a widespread scatter of the name white and, allowing for this, more colours were called red and less were called green or blue. The name purple did not appear.

15. General Conclusions.

The results in this paper are intended as a contribution to knowledge of colour recognition, and are not regarded as a complete statement of the distribution of the simple colour names over the colour chart. In one or two instances the observations have given direct indication of the suitability or otherwise of certain signalling colours, and these are summarised below.

Blue and purple cannot be regarded as satisfactory signal colours. Blue would be safe if the colour were highly saturated and if the illumination were very high, requiring a glass of low transmission and a high-intensity lamp, but a reduction in the illumination would increase the risk of confusion with white or green. Purple is not a safe colour, and its use must rest entirely on its recognition as a dichromatic light.

Red is the ideal signalling colour, being recognised down to low illuminations and yet being very easily produced. In general, a spectral red whose hue wavelength is longer than 610mμ (0.667X+0.333Y + 0.000Z) is a safe signal colour, if orange lights are not also seen by the observer as signals or as extraneous lights. If orange lights are to be seen, a darker red becomes necessary. Red colours may be considerably desaturated without danger of confusion.

Green is a safe signalling colour under any usual conditions, but must be considerably restricted if confusion with blue would cause danger or misunderstanding. The blue limit has not been sufficiently investigated in these experiments, but the requirements of total transmission are likely to prevent signals approaching this limit. On the yellow side the hue wavelength should be less than 550mμ, and to avoid confusion with white the colour should be more saturated than a point approximately 0.25X + 0.40Y + 0.35Z.

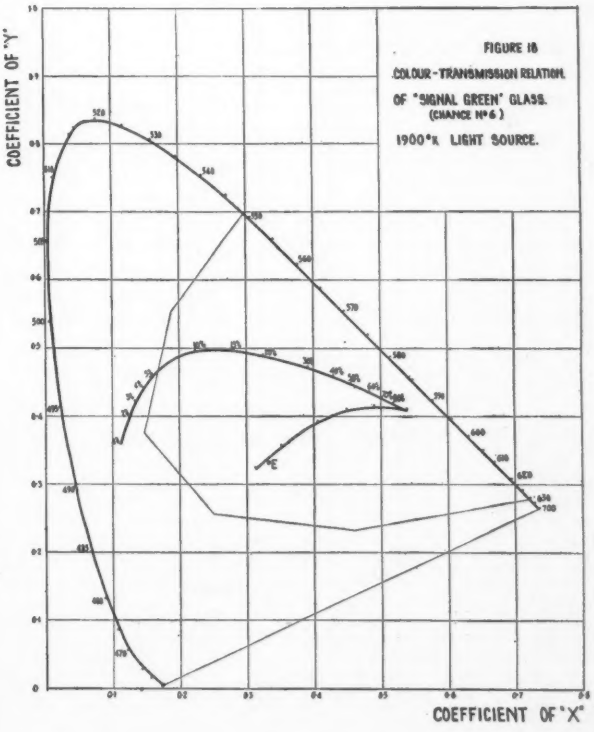
Yellow and white colours are safe if used separately, but they cannot be used together unless the white is of high colour temperature. For yellow signals hue wavelengths less than 590mμ seem unsafe when any type of white is also used, and hue wavelengths greater than 596mμ seem liable to confusion with red signals at low intensity. Yellow colours need not be fully saturated unless there is danger of confusion with low temperature white colours. If white lights are not to be used as signals, and will not be so placed as to be confused with signals, yellow colours down to 583mμ would appear to be safe for signalling purposes. As a general rule, white colours below 2800°K are liable to confusion with yellow by a dark adapted observer, although subjective white is always a very variable quantity.

There is no significant difference between the monochromatic sodium yellow light and the light of the same hue wavelength given by a filter and incandescent filament lamp under normal conditions.

16. The Calculation of the Optimum Tolerance for Colour Filters.

It has already been pointed out that the choice of a colour specification must rest on a compromise between high recognition and high light transmission of the colour filter, and an example of the way in which the compromise may be reached will serve as an example of the use of the colour recognition data.

The relation between colour and transmission of the common signal glasses is known to be fairly constant [14] and may be expressed in the form shown in Fig. 18, where the locus of the colour given by



increasing thickness of " signal green " glass (Chance No. 6 Contrast Filter) with an oil lamp at 1900°K is marked with a scale showing the corresponding percentage transmissions. Comparison between this relation and the recognition contours in Series I. will

give the transmission of glasses corresponding to certain recognition levels at each of several illuminations. These figures are set out in Table 18.

TABLE 18.
Recognition and transmission for signal green.

Illumination (s-m.c.)	1	6	10	100	3,400
% Recogn. level of green (RYGBPW choice)	Percentage transmission of signal green (1,900°K light source)				
90	—	3—14	1.5—13	—	—
80	—	1—17	18	5—10	10
70	1—5	20	19	14	7—15
60	10	22	21	17	4—21
50	12	23	22	20	3—24
40	15	25	24	24	28
30	17	26	26	27	31
20	20	27	30	32	34
10	27	30	37	38	37

The distance at which the appropriate illumination is given by a particular lamp and a colour filter of known percentage transmission may be calculated from the relation:

$$d^2 = I.t/100.E$$

where d is the distance (sea-miles)
I the intensity of the lamp (candles)
t the percentage transmission of the filter
E the illumination (sea-mile candles)

No allowance is made for atmospheric absorption in the above relation.

The results of this calculation are given in Table 19 for a 20 candle-power lamp at 1900°K, which was chosen as typical of the lamps likely to be used for short-range signals with signal green glass. Incidentally, this is a good basis for comparing the results obtained with different conditions, and it will be seen from the two tables and the diagram that the consistency is reasonably good.

TABLE 19.
Recognition and range for signal green.

Illumination (s-m.c.)	1	6	10	100	3,400
% Recogn. of Green (RYGBPW choice)	Distance from 20 c.p. lamp (sea-miles)				
90	—	0.31–0.68	0.18–0.51	—	—
80	—	0.18–0.75	0.59	0.10–0.14	.025
70	0.44–1.0	0.81	0.62	0.17	.020–.030
60	1.41	0.85	0.65	0.17	.015–.035
50	1.55	0.87	0.66	0.20	.010–.037
40	1.73	0.91	0.69	0.22	.041
30	1.85	0.93	0.72	0.23	.043
20	2.0	0.95	0.77	0.25	.045
10	2.3	1.0	0.86	0.28	.047

By plotting the transmissions in Table 18 against the distances in Table 19 a family of curves (Fig. 19) is obtained showing the distances at which the colours of glasses of certain transmissions are identified with certain degrees of recognition, in the RYGBPW choice with a 20 c.p. lamp. The points are joined by straight lines, each curve relating to the percentage recognition marked against it. The chain-dot curve at the bottom of the diagram represents 0.5 sea-mile candles illumination and, as all the curves must return to zero distance at zero transmission, they will approach some such limit as this. A smooth curve has been drawn through the 70% recognition points.

It will be seen that below 70% recognition level the greatest distance is given by the glass of lowest transmission, indicating that increased purity of colour is of greater value than increased light transmission. If the different curves are rounded off in the same way as that for 70% recognition, they show a maximum distance to be given by a transmission of about 13%. The smoothed curve for 70% recognition shows an optimum transmission of 12.5% and over 95% of the maximum distance is given by a transmission tolerance from 9% to 16%. These values are independent of the intensity of the lamp, but are directly dependent on its colour temperature. The curve for 70% recognition is fairly complete for this glass as the 70% contour intersects the colour transmission locus twice at one s-m.c. and twice at 3400 s-m.c. It is appropriate to note that the limiting transmissions specified by the Board of Trade and the Ministry of Transport are 10% and 15% for this combination of glass and lamp.

Curves such as Fig. 19 can only be drawn when a series of different illumination levels has been investigated, as in Series I., but isolated points may be

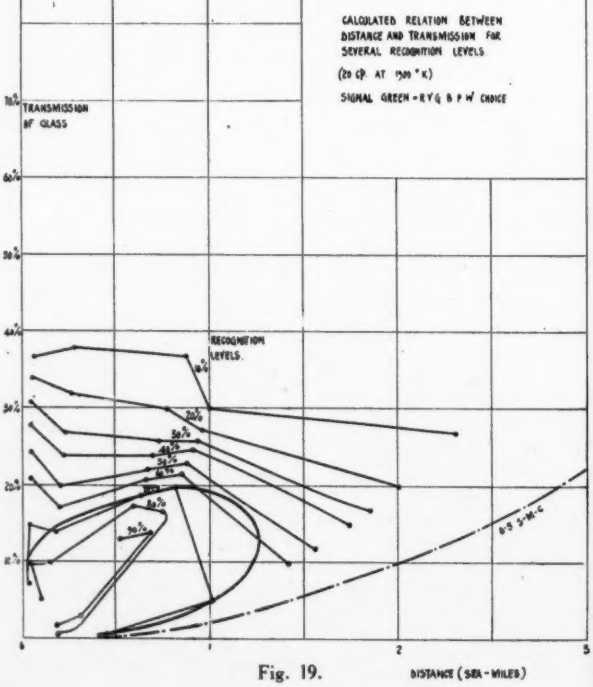

CALCULATED RELATION BETWEEN DISTANCE AND TRANSMISSION FOR SEVERAL RECOGNITION LEVELS
(20 CP. AT 1900 °K)
SIGNAL GREEN - RYG B P W CHOICE
TRANSMISSION OF GLASS
RECOGNITION LEVELS
0·5 S-M-C
DISTANCE (SEA-MILES)

Fig. 19.

calculated when there is only one illumination level. For the Series I. results similar curves could be drawn for any of the types of coloured glass, although some of the curves would contain irregularities caused by the variable recognition of blue and purple colours and by small inconsistencies between the results for different illumination levels.

Calculations for signal green glass with 2360°K and 2848°K and for emerald green glass (Chance No. 5 Contrast Filter) with 1900°K, 2360°K, and 2848°K have yielded similar results which are summarised in Table 20.

TABLE 20.

Optimum transmission and maximum range.

Glass	Lamp	Max. Dist. for 70% recogn. (sea-miles)	Optimum transmission	Transmission tolerance (95% range)	Illumination at max. range (s-m.c.)
Signal green	20cp 1,900°K	1.25	12.5%	9%–16%	1.6
	2,360°K	1.5	16%	10%–20%	1.4
	2,848°K	1.9	12%	—	0.7
Emerald green	20cp 1,900°K	1.0	8%	5%–12%	1.6
	2,360°K	1.25	13%	8%–18%	1.6
	2,848°K	1.65	20%	12%–26%	1.5

The combination of signal green glass with 2848°K is not satisfactory, as this glass was designed for use with oil lamps, and the colour is liable to confusion with blue.

A check on these calculations is given by measurements made by Mr. H. N. Green and communicated privately to Dr. Hampton, of Messrs. Chance Brothers and Co., Ltd., in April, 1931. These measurements were made with a yellowish variety of signal green glass and a lamp operated at 17 l/w (2900°K) approx., and Fig. 20 shows the distances at which glasses of different transmissions were recognised, although the criterion was not so much the recognition of the green colour as the detection of the signal itself and the recognition of its difference from red and white. The curve is the same general shape as the lower recognition levels gave in the calculations above, but it should be pointed out that this curve was obtained with a 54 c.p. lamp whereas the calculations relate to a 20 c.p. lamp.

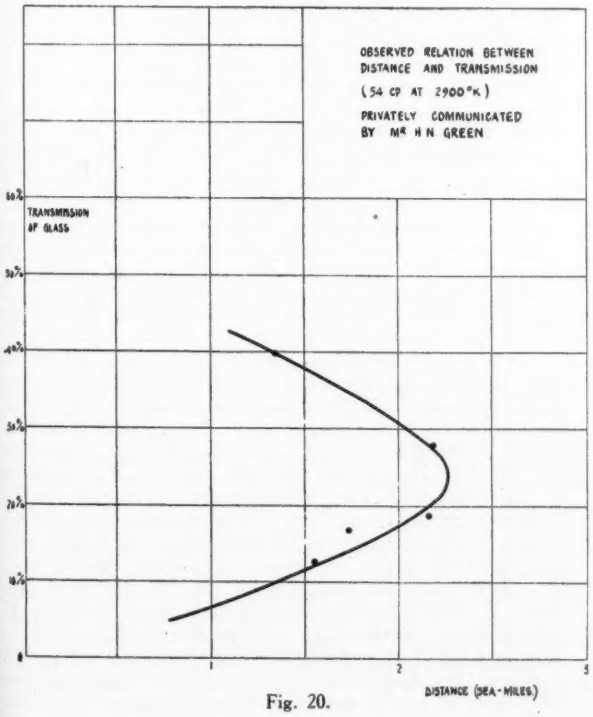


Fig. 20.

17. Acknowledgments.

Acknowledgment is due to the six selected observers for the very considerable work given by them and to the remainder of the fifty observers. Mr. A. Dinsdale, M.Sc., was responsible for operating the 11-primary mixer and for analysing the observers' reports, and the author is greatly indebted to him, and also to Mr. D. A. Nicholls, B.Sc., who assisted in the later experiments on the 4-primary mixer. Invaluable help and encouragement has been given by Dr. W. M. Hampton, with whom the work was discussed in many of its stages, and the author's thanks are due to him and to the other directors of Messrs. Chance Brothers and Co., Ltd., for enabling the work to be done and permitting it to be published.

APPENDIX.

Characteristics of the Fifty Observers.

Observer No.	Occupation	Age	Sex	Colour Recognition experience	Debit marks by simple ranking	Debit marks (weighted ranking)
1*	Electrician	40	M	None	22	
2	Glass designer	29	F	Paints and Pigments	32	
3*	Physicist	30	M	Colorimeter and field	34	
4	Warehouse foreman	49	M	Coloured glass	35	31
5*	Chemist	38	M	Little	36	
6*	Chemist	22	M	None	36	
7	Clerk	45	M	None	36	
8	Secretary	20	F	None	38	36
9	Coloured glass sorter	35	M	Considerable	38	
10*	Instrument maker	42	M	None	39	
11	Lighthouse draughtsman	31	M	Field observations	40	
12*	Physicist	22	M	Colorimeter.	40	
13	Glass inspector	22	F	Little	41	
14	Glass inspector	34	F	Little	41	
15	Physicist	18	M	Little	42	
16	Physicist	26	M	None	44	
17	Secretary	23	F	None	45	
18	Engineer	20	M	None	45	42
19	Sales manager	27	M	None	46	
20	Chemist	40	M	None	46	
21	Chemist	18	M	Little	47	
22	Works manager	29	M	Little	47	

* Selected observers.

Observer No.	Occupation	Age	Sex	Colour Recognition experience	Debit marks by simple ranking	Debit marks (weighted ranking)
23	Warehouse manager	36	M	Little	48	
24	Engineer	23	M	Pyrometry	50	50
25	Chemist	30	M	None	50	
26	Warehouse manager	27	M	Little	51	
27	Electrical Engineer	29	M	None	52	
28	Physicist	43	M	Colorimeter and field	52	
29	Glass storekeeper	41	M	Coloured glass	52	
30	Sales engineer	26	M	None	54	
31	Shop foreman	47	M	Coloured glass	54	
32	Physicist	25	M	Colorimeter	55	
33	Secretary	32	F	None	56	
34	Works manager	34	M	Little	57	
35	Engineer	24	M	None	58	62
36	Warehouse foreman	30	M	Little	59	
37	Physicist	24	M	Little	61	60
38	Shop foreman	38	M	None	64	
39	Draughtsman	54	M	Little	72	74
40	Coloured glass sorter	39	M	Considerable	74	
41	Works manager	49	M	None	74	
42	Instrument maker	19	M	None	75	
43	Foreman	35	M	None	78	75
44	Storekeeper	38	M	None	79	82
45	Draughtsman	59	M	None	82	
46	Coloured glass sorter	52	M	Considerable	82	
47	Foreman	58	M	None	89	99
48	Foreman	44	M	None	92	
49	Coloured glass sorter	63	M	Considerable	94	
50	Foreman	43	M	None	111	

Method of Grading the Observers.

Each observer recorded one of six names for each of the 256 test colours, and it was required to find which observers most frequently gave the same name to each test colour as the majority.

The first method was to take the 236 colours which had received a particular name on 50 per cent. or more occasions, and to give each observer a debit mark each time he chose a different name from the majority. The observer with least marks would then be nearest the average—the debit marking by this method is given in column 6 of the above table.

This method has the advantage of simplicity, but it seemed that an observer who dissented from a 90 per cent. majority should be debited more heavily than dissention from a 50 per cent. majority. The investigation was therefore carried a stage further by weighting the debit marks according to the distribution of names given to the colour.

Suppose for a given colour, M per cent. of the observers gave the majority choice and N per cent. gave some other choice. An observer giving the name chosen by the N per cent. would receive a debit mark of $(M-N)/M$, and an observer in the majority column would receive zero debit.

These weighted debit marks were calculated for eleven observers taken at random, ranging from good to bad according to the first method of ranking, and the correlation between the two orders of ranking was 0.97. This indicated that the methods were not unsound, and that the selection of six could be relied upon to have given average observers. The debit marking by the second method is given in column 7 of the above table.

The selection of the six observers marked with an asterisk depended to some extent on the time they could spare, but the differences between the results of any in the first twelve were not significant.

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DISCUSSION

Dr. W. M. HAMPTON, remarking that he had had an opportunity of criticising this work before it was published, said it had been going on for some five years, nearly continuously, and it had not only involved considerable skill and patience, but also a considerable amount of tact because it was not easy to get fifty people to spend a great deal of time doing an unpleasant job in which they could see no sense! The result had been to provide a sound basis for others to continue the work in the future, and to enable comparisons to be made from observations in different parts of the world. Standard forms of colour representation could be drawn up, based on the author's work, and although the details might not be repeated with individuals they would be an average of all the people going about. When one realised the differences between the specifications which had been issued, any step like that would be an enormous advance. He believed that Mr. Good at the B.S.I. had been very anxious, when war interrupted the work, to start a committee to look into the possibilities of correlating the various colour specifications. As the result of the present paper it rather seemed that one could draw two contradictory conclusions. In the first place it was obvious that one over-riding specification could be drawn up which would cover the different ones that now existed. On the other hand, it was reasonable to take the line that the specification could vary according to the choice of names that was permissible to the observer. This implied that the restriction upon the road user, for instance, were he given the specification necessary

for a mariner, would be onerous. Which of these two lines of thought should be followed is a matter for further discussion, but whatever the line taken in devising standard specifications he felt that the fundamental bases had been presented in this paper.

Mr. N. E. G. HILL pointed out that before the results of an investigation of the kind described in this paper could be used they must be examined very closely to see precisely what they meant. What was usually meant by a "red recognition curve?" Usually such a curve represented the *probability* that certain signals. seen under certain conditions, would be recognised as red; and this implied that a large number of observations were made by a large number of observers to obtain a statistical average. In order to obtain such a curve an experiment in probability must be performed, and the significance of the results would be governed in a very large measure by the method of the experiment. The author's experimental procedure must, therefore, be examined very closely in order to assess the value of his results.

It appeared from the paper that the author used 256 different coloured signals, of a particular intensity, and showed each signal *once* to *each* of 50 observers. On the basis of the observers' response to this test the author then selected six of the 50 observers and labelled them "average observers." These six observers were used for his subsequent tests. Now the notion of an average observer, in the usual sense of the words, implied not only a large number of observers from whom to select the average observer, but also a further condition with regard to the individual observer, namely, that he himself took a large number of observations in order to find his average response.

In a subjective observation of the kind considered here, the observational scatter for a single observer was fairly wide, and a considerable number of observations was required to give significance to their average. In other words, an observer could only be classed as "average" on the basis of his average observation. It was not possible to make such a classification on the basis of a single observation as the author had attempted to do. In fact, by choosing his observers in this manner the author had tacitly assumed that an observer's first observation of a particular signal was the same as his average observation. This assumption was contradicted by practical experience.

In the tests with the chosen six observers a similar argument applied. The author showed each signal not more than three times to each observer. Since most of the signals were likely to be recognised, at least occasionally, in, say, three of the colour categories, it was clear that three observations were not nearly enough to be significant. It must, therefore, be concluded that not only were the six observers not necessarily the average of a larger number, but also that the results given in the curves did not necessarily represent even the average observations of the chosen six. In other words, the probable error of the curves was very large, so large that it was doubtful whether any significance can be attached to them.

About two years ago the present writer completed an investigation of the recognition of coloured light signals, giving 1 mile-candle and 2 mile-candles illumination at the eye, involving over 30,000 observations. The investigation was designed primarily to obtain data for aviation light signals. During the experiments the author visited the writer, saw his apparatus and discussed the experimental procedure with him. The general method of the experiment was the same as the author had described in his paper, but with the difference that each of the present writer's nine observers saw each signal 20 times over a considerable period of time. The importance of securing a number of observations from each observer in order to obtain an average seemed so obvious that the point was not stressed in the report which was made available to the author during his own investigation.

It was to be noted that the author's curves bore superficial resemblance to the results of the writer's investigation, and many of his conclusions were in agreement with the writer's, but this agreement could only be regarded as fortuitous, because, as had been shown, the probable error of the author's work was very large and could not be assessed.

Dr. W. D. WRIGHT congratulated the author on the enormous amount of work he must have done in carrying out this investigation. One point of interest was that the observers were able to recognise the signals rather more easily if they were just flashed on for a second at a time, than was the case if the signals were continuous. It seemed that the eye responded most successfully when it was seeing a thing for just a short space of time and not continuously. Apparently, some form of adaptation was going on. It was mentioned in the paper that the blue-green and green could not be used together in any signalling system, a result that he had observed himself, but he could not understand why these two colours were confused so easily. He would like to see Mr. Holmes's results plotted on the Uniform Chromaticity Scale (the author here showed a slide of Fig. 16), especially as the C.I.E. Chart was very elongated at the top. He wanted to ask the author whether this accounted for the rather large area in the chart included in the specification of the green filters but which the author had not been able to cover in his tests. He felt the differences in some of the specifications were apt to be over-emphasised when plotted in the C.I.E. system.

Continuing, Dr. Wright said he was surprised at the difference in the shape of the yellow contours as the intensity was changed; he certainly would not have anticipated this. The somewhat anomalous behaviour of the blue was also of interest, and it may be further evidence that the blue response is in some way different from the red and green, a conclusion supported by other researches carried out in recent years. Judging, however, from its position in the colour chart, the author's blue was surprisingly desaturated.

Mr. J. S. Dow remarked upon the difficulty in distinguishing between blue and green at a considerable distance. He would like to know how far this was due to atmospheric absorption, which might diminish the

difference in quality of the two sources examined, and how far to peculiarities of the human eye. He was inclined to think, for example, that the chromatic aberration of the eye might prove to be an important factor in judging the colours of distant lights. Could the author say whether this was a constant quality, or did it, like colour sensitiveness, differ in individuals? If the effect was variable, and occasionally serious in its effect on judgment of colour, it would be logical to examine people for chromatic aberration under conditions where tests of colour blindness were usually prescribed.

He recalled a paper he had read before the Society many years ago in which this effect was discussed. He himself as one of those people who, when looking at a distant lamp-filament through cobalt glass, saw the source as a red spot with a halo of blue around it, which meant that at that distance he could not focus the blue rays. He believed that this inability to focus blue light was often an influence in the perception of coloured light, for example, it might be in part responsible for the apparent "spread of light" in streets lighted by mercury vapour lamps. He had the impression that most people had the same experience as himself, in being unable to focus distant blue light, but there were some who had the opposite experience, and he recalled at least one person—Dr. Louis Bell, from the United States—who could focus equally well on either the red or the blue, but not simultaneously.

Dr. W. M. HAMPTON said it should be emphasised that this paper dealt only with the beginning of a great deal of work on the subject. On the other hand, the results so far obtained agreed with the accepted colour specifications which were based entirely on practical experience. He believed it was the German railway specification which called for yellow-green glasses, and said that blue-green would not do. Japanese specifications, on the other hand, said that blue-green glasses were satisfactory and that yellow-green would not do. Both these specifications presumably were found satisfactory in practice, and Mr. Holmes had now shown that both yellow-green and blue-green glasses appeared the same when viewed as point sources.

Mr. R. MAXTED remarked that he would like to congratulate Mr. Holmes not only upon the great value of the investigation he had made but on the skilful manner in which he had elucidated so complex a subject. Mr. Maxted did not feel in a position to comment on the technical details of the paper, but there were certain aspects in which he felt an especial interest. Mr. Holmes had given an excellent demonstration of the need for deriving objective data from the investigation of subjective values and of the fact that this was a practicable process. This is of vital importance to those concerned with any aspect of light and vision. In the course of investigation of visual phenomena, one often met the statement that diametrically opposite opinions were to be expected from quite well-informed individuals and that no definite conclusion could be reached. The author had shown that was not necessarily the case and that useful objective data could often be extracted from the apparent chaos of the subjective problem. Success in this respect did, however, demand a clear conception of the information sought and care in the method of extracting information from the average observer. The author was to be congratulated on his treatment of this particular difficulty, and on his recognition of the importance of avoiding creating confusion in the observer's mind and, especially of abstaining from methods liable to provoke an uninformed opinion. The essential need was to reduce the problem to a simple form and to elicit a clear-cut decision based on the observer's own experience.

Mr. J. W. PERRY said that owing to the dependence of colour recognition upon brightness and contrast such systematic plotting upon the colour chart of colours as recognised under different conditions of observation could provide valuable information. A yellow illumination might, for example, change toward green at a lower brightness level. In actual practice the recognised colour of signals might be affected by contrast with the background or with other sources within the field of view.

The PRESIDENT mentioned three matters. The first was with regard to the apparent colour of the filament of a tungsten lamp the voltage of which was being slowly reduced. In these circumstances the filament gradually became invisible in the dark. The general impression made on an observer, who is dark adapted, of the colour of such a filament at the stage when it is still just visible, was said to be grey. Could the author place that on his colour chart?

The second point related to luminous signs having letters of different colours. When one looked at such a sign, some of the letters stood out being apparently a different distance away compared with the others. He had drawn the attention of many of his friends to that fact, but some could not see it at all. Others, including their old friend Mr. Trotter, could see the effect, but did not place the colours in the same sequence.

Finally, the President referred to the difference between laboratory results and those obtained in the open. This investigation had taken a very long time, and it was a tribute to a great industrial firm to have concentrated such a large amount of time and effort in getting out the results in such a form. Firms of this character had to produce financial results, and therefore it was all the more credit to them when they turned out a piece of work which, although at the present moment had not much obvious practical bearing, would undoubtedly be of great service in the future.

Obviously, added the President, in carrying out experiments in the laboratory, the question of the atmosphere between the observers and the instrument was of no importance unless the observers were allowed to smoke. (Mr. Holmes: No.) On the other hand, if the experiments were carried out in the

open the atmosphere toned down the colour very often. It changed the quality of the light, and therefore it was to be expected that laboratory results might be capable of being repeated whereas those done in the open would have a much wider variation. Moreover, we should always look for variation in one direction, viz., that of causing the light to get more red as it passed through long stretches of atmosphere.

Mr. J. G. HOLMES, replying first to the president, said that a barely-luminous filament would appear red and not grey if examined by direct, foveal vision, but there was a great tendency to use the extra-foveal retina in threshold observations and under these conditions there would be little or no sense of colour. The point about luminous signs, raised by the president, was closely related to Mr. Dow's question as to whether different people had different chromatic aberration. Chromatic aberration was substantially constant from one observer to another, but the central point of the spectrum on which any particular person focused was very variable owing to some people being long-sighted and others short-sighted. This meant that some people saw blue letters indistinctly, whereas others saw red letters indistinctly. There was a further difference, due to the fovea being off the optic axis of the crystalline lens of the eye, which meant that the binocular sense of distance would be different for red and blue lights against a black background, and therefore that some letters might appear to be at a greater or less distance and of greater or less size. With regard to the president's last point, the work had been undertaken on the laboratory scale so as to eliminate the variables always associated with field experiments—atmospheric conditions, temperature, rain, and so on—which made it very difficult to maintain high intensity colour signals at a constant value.

Replying to Mr. Hill, he said he would have liked to study Mr. Hill's report (Reference 11 above), which had been issued confidentially, and which described a line of attack parallel to his own, both having developed, he believed, from the report of the author's preliminary experiments presented by Dr. Hampton at Berlin in 1937 (Reference 15 above). He hoped that the ban imposed by the Official Secrets Act would be lifted and that Mr. Hill's results could be published, as he believed them to be of equal value with his own, but in the meantime he had had to exercise discipline and abstain from reading it, so as to keep the two sets of experiments entirely independent. Work such as this must always be regarded as an individual contribution to knowledge and must be presented in a form suitable for examination and correlation at a later date in much the same way as the preparatory work on the visibility curve. In this respect he fully agreed with Mr. Hill that close examination was necessary, and he regretted that the full script was not available for Mr. Hill to study before he made his criticism. To find a truly average observer would involve an inestimable amount of work and might well prove impossible, and all that was necessary was to ensure that the selected observers were not abnormal.

The probable error of a curve depends largely on the probable error of each measurement and on the number of measurements, and it was obvious that many measurements must be made along the curve. In the author's experiment it was required to find a contour in unknown country, and the experimental method was deliberately chosen to cover a large number of observed points whose character and distribution were comparable with signals used in practice. The author's early work was demonstrated to Mr. Hill's senior before his experiments were commenced, and doubtless he, too, made a deliberate choice of experimental method although it had been pointed out in the discussion by Mr. Dinsdale, who had studied Mr. Hill's report, that he had not covered all the signalling colours, and had not reproduced their spectral energy distribution. Mr. Hill's report or results were not, as had been stated, made available to the author during his own investigation and no useful purpose is to be served here by attempting to make comparisons between the results.

Commenting on Dr. Wright's question regarding the area of the colour chart covered, the colour mixer was limited by the requirement of 5 per cent. or greater for most of the primary filters, in order to give higher illuminations as well as threshold, and this ruled out the region close to the green-blue spectrum. It was an experimental fact in practical signalling that blue-green and blue quickly became similar as the illumination was reduced, as Dr. Hampton had emphasised, and he could not answer whether this was psychological or physiological in the eye of the observer, or to what extent it was influenced by atmospheric absorption, as suggested by Mr. Dow. These were all variable quantities which worked in the same direction, reducing the illumination from a blue signal.

An interesting point had been raised by Mr. Dow regarding cobalt glass which had the peculiarity that in addition to the blue transmission there was a narrow band of red transmission. Both red and blue could be seen and the state of adaptation of the eyes of the observer determined whether the red rays or blue rays came into focus.

In reply to Mr. Perry on the question of the yellow region, a large number of yellows had been included deliberately in view of the various queries as to what yellowcolour ought to be used for signalling and it was required to test a wide range of yellows in comparison with white under conditions of dark adaptation. The change from the yellow name towards the green name at a lower illumination level was borne out by the results shown in the diagrams. As to the questions of background, these experiments had been made with a virtually black background, this being the only reproducible condition similar to practical conditions.

APPLICATIONS FOR MEMBERSHIP.

At a sessional meeting held on June 24, 1941, the list of applicants for membership, whose names had been announced at the previous meeting on May 13, 1941 (Trans. Illum. Eng. Soc., Vol. VI., No. 4, p. 60, June, 1941), was again presented, and these gentlemen were formally declared members of the Society.

In accordance with the procedure outlined in the Revised By-Laws the following applicants have been duly elected by the Council to Membership in the Society and their names have been added to the list of members:—

CORPORATE MEMBERS:—

Alger, T. E. .....160-1, Dock Street, NEWPORT.
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Browning, W. .....37, Brown Street, MANCHESTER, 2.
Carne, J. B. .....The South Metropolitan Gas Company, 709, Old Kent Road, LONDON, S.E.1.
Chubb, C. S. .....Mining Department, University College, Newport Road, CARDIFF.
Dinham, J. H. .....Electricity Offices, St. Mellow, CARDIFF.
Harrison, T. Scott .....The British Thomson-Houston Co., Ltd., 5, Northampton Gardens, SWANSEA.
Ireland, E. J.....29, Oxford Street, BRISTOL.
Jones, Edward .....Electricity Department, The Hayes, CARDIFF.
Jones, T. David .....Mining Department, University College, Newport Road, CARDIFF.
Luen, A. E. .....17, Dumfries Place, CARDIFF.
Mabbett, H. W. .....21, Ashfield Road, Newbridge, MONS.
Martyn, A. J. .....77, The Ridgeway, LONDON, W.3.
Nelson, J. H. .....c.o. Joseph Lucas, Ltd., Great King Street, BIRMINGHAM.
Quinn, W. L. .....28, Ravenswood Drive, GLASGOW, S.1.
Ward, H. .....15, Northgate, DEWSBURY.
Wilkins, B. C. .....28, Heath Park Avenue, CARDIFF.

STUDENT MEMBER:—

Anderson, R. W. .....97, Victoria Road, LEEDS, 6.

I.E.S. Fellowship.

The following Application for Fellowship has been accepted by the Council:—

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Cotton, H. .....Electrical Engineering Dept., University College, NOTTINGHAM.
Charity, J.C. .....182, Rutland Road, West Bridgford, NOTTINGHAM.
Ellis, R. H.....c/o Crompton Parkinson, Ltd., Broadway, NOTTINGHAM.
Elkin, W. .....77, Derby Road, Beeston, NOTTINGHAM.
Greaves, T. H. .....34, Stamford Road, West Bridgford, NOTTINGHAM.
Harris, W. J. .....26, Bothwell Street, GLASGOW.
Honnoraty, G. .....60, Park Lane, Castle Donington, Nr. DERBY.
Hadfield, G. C. .....Flat 2, 91, Forest Road, NOTTINGHAM.
Hood, E. M. .....The British Electrical Development Association, 425, Sauchiehall Street, GLASGOW.
Hacking, A. .....32, St. Leonards Drive, Wollaton, NOTTINGHAM.
Johnson, G. D. .....Kingswood, Bulcote, NOTTINGHAM.
Jones, W. H. .....10, Arnold Grove, Shirley, BIRMINGHAM.
Lappin, T. M. .....Public Lighting Department, 1, Lochee Road, DUNDEE.
MacKerron, H. G. ...15, Berkeley Street, GLASGOW.
Mountford, G. R. .....6, Landmere Lane, Ruddington, NOTTINGHAM.
Mills, G. A. .....7, Harrow Road, West Bridford, NOTTINGHAM.
Meadows, L. .....47, Waterloo Street, GLASGOW.
MacLeod, J. Macfarlane .....7, Elmbank Street, GLASGOW.
Phillips, E. G. .....Arshus House, Annesley Grove, NOTTINGHAM.
Pickford, R. J. .....74, Thackerays Lane, Woodthorpe, NOTTINGHAM.
Smith, S. A. .....51, Middleton Boulevard, Wollaton Park, NOTTINGHAM.
Rainbow, H. .....295, Wollaton Road, NOTTINGHAM.
Small, G. C. .....2, Highfield Road, East Nuthall, NOTTINGHAM.
Strachan, D. A. .....Metropolitan Vickers Electrical Company, Ltd., No. 1, Kingsway, LONDON, W.C.2.

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MOTOR CAR WARTIME HEADLAMP MASKS

By J. F. STANLEY *(Member)*

(Paper read on March 11, 1941).

At the outbreak of war the first edition of the Lighting (Restrictions) Order was issued, and in the section dealing with the lights carried by road vehicles the use of headlamps on motor cars was virtually prohibited since no lamps of a power exceeding 7 watts were allowed. A few days later a statement was made that it had been decided to relax the restrictions on the use of headlamps and that a new Order would shortly be issued. In the meantime the use of headlamps would be allowed, provided the front glass was completely obscured except for an aperture of a semi-circular shape 2 in. in diameter with the base uppermost. The lower half of the reflector had to be completely blacked out up to a distance of ½ in. above the centre line of the reflector. Only the near-side headlamp could be used.

The polar distribution of light from a typical headlamp treated in this manner, taken with a 36-watt V-filament lamp, shows a maximum of about 40 candlepower. The horizontal value is 13 candles, and the intensity becomes zero at ½ deg. above the horizontal. The distribution of illumination along a road is shown in Fig. 1 (Curve A). It will be seen that there is a very bright patch of illumination on the road close to the lamp. This bright patch is disconcerting to the driver and is visible from the air. At 28.6 ft. from the lamp the illumination has fallen to 0.002 ft.c. This headlamp gave an inadequate driving light with excessive foreground light, and was very sensitive to inaccurate adjustment which might cause dazzle.

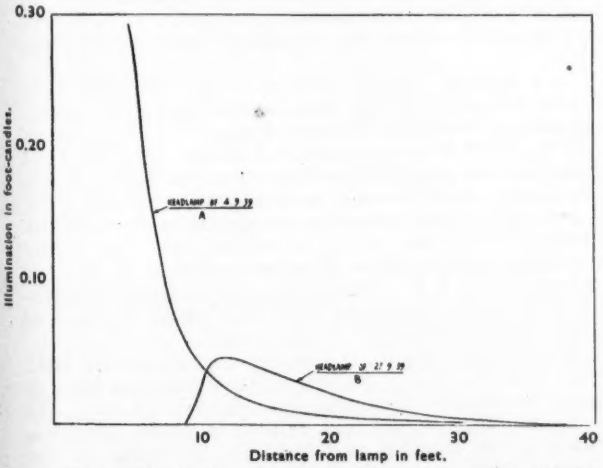


Fig. 1. Illumination of road surface (Horl. foot-candles. Headlight at 2 ft.).

On January 29, 1940, a new edition of the Lighting (Restrictions) Order was issued. In this Order the requirements with regard to headlamps were amended and the use of a particular type of headlamp mask was virtually enforced. It could be fitted to either the near-side or off-side headlamp, and the design was such that the light is emitted in a restricted angle in the vertical sense. With a 36-watt lamp the maximum intensity obtained is about 100 candles, but in some masks this is as high as 150 or 250 candles. When properly adjusted the direction of the beam of maximum intensity is about 6 deg. below the horizontal.

The illumination of the road surface is shown in Fig. 1 (Curve B). It will be seen that no light falls on the road within 10 ft. of the front of the vehicle. This portion of the road cannot be seen by the driver of the vehicle as the radiator and the wings are in the way. Consequently, to illuminate this portion of the road does not help the driver, but increases visibility from the air. At a distance of 28.6 ft. from the lamp the illumination on the road is about 0.006 ft.c. Elsewhere the illumination is between two and three times that given by the lamp previously described. This headlamp gives a reasonably good light for seeing the road surface without excessive foreground brightness, and the adjustment for avoidance of glare, while still fairly critical, is not so critical as for the other headlamp. The use of this mask, which will be described as the "Home Office mask," was virtually enforced on January 29, 1940, but details of the design and samples were available some weeks earlier. The first public disclosure of the design was in a memorandum on "War-time Lighting Restrictions—Lights Carried by Road Vehicles," which was issued by the Ministry of Home Security on September 30, 1939.

On October 3, 1939, the first meeting of a special subcommittee of the Joint Lighting Committee was held, the terms of reference being to make a comprehensive survey of the essentials for a headlamp mask and to prepare a specification. The committee's first task was to study the characteristics of the Home Office mask from the point of view of glare, visibility of road signs and obstructions, etc. Various investigators carried out tests and made suggestions for modifications to the design with a view to obtaining an improved performance and producing a mask which would be less critical in adjustment. All this occupied some time. It was eventually decided that, rather than endeavour to draw up a specification for an improved design, it would be better to issue a detailed specification for the Home Office mask with the idea of securing greater uniformity in performance, and to supplement this at a later date with a specification based on performance only.

The main characteristic of the Home Office mask is a sharp cut-off at the horizontal. From the point of view of glare it is desirable that the cut-off should be slightly below the horizontal, but this is not practicable having regard to the foreshortening of the visible area which would thereby result. It has already been mentioned that a limit is set upon the

maximum angle from the horizontal at which light should be emitted.

Theoretical Requirements.

The maximum intensity is of the order of 100 to 250 candles and it is interesting to compare this with theoretical requirements. From the point of view of visibility from the air, calculations were made to determine the maximum intensity permissible, such that an observer flying at 5,000 ft. would be unable to see the light when looking down at an angle of 1 in 20 (2.86 deg. from the horizontal). This corresponds to a distance of nineteen miles, and the figures for the maximum intensity are:—

Perfect atmosphere	72 candles
Very clear	530 candles
Average clear night	5,000 candles

From the point of view of visibility of obstructions on the road, it was considered that the intensity should be such that a white object 0.5 sq. ft. in area could be detected at a distance of 100 ft. along a level road. This requires 8 candles. If the mounting height of the headlamp is 2 ft. 6 in. a distance of 100 ft. along the road is equivalent to an angle of 2 deg. below the horizontal, and at this angle a Home Office mask gives about 20 candles. It is therefore apparent that the light given by the mask is above the theoretical minimum as regards visibility of obstructions, while the light will not be visible from the air on a clear night under the conditions stated above.

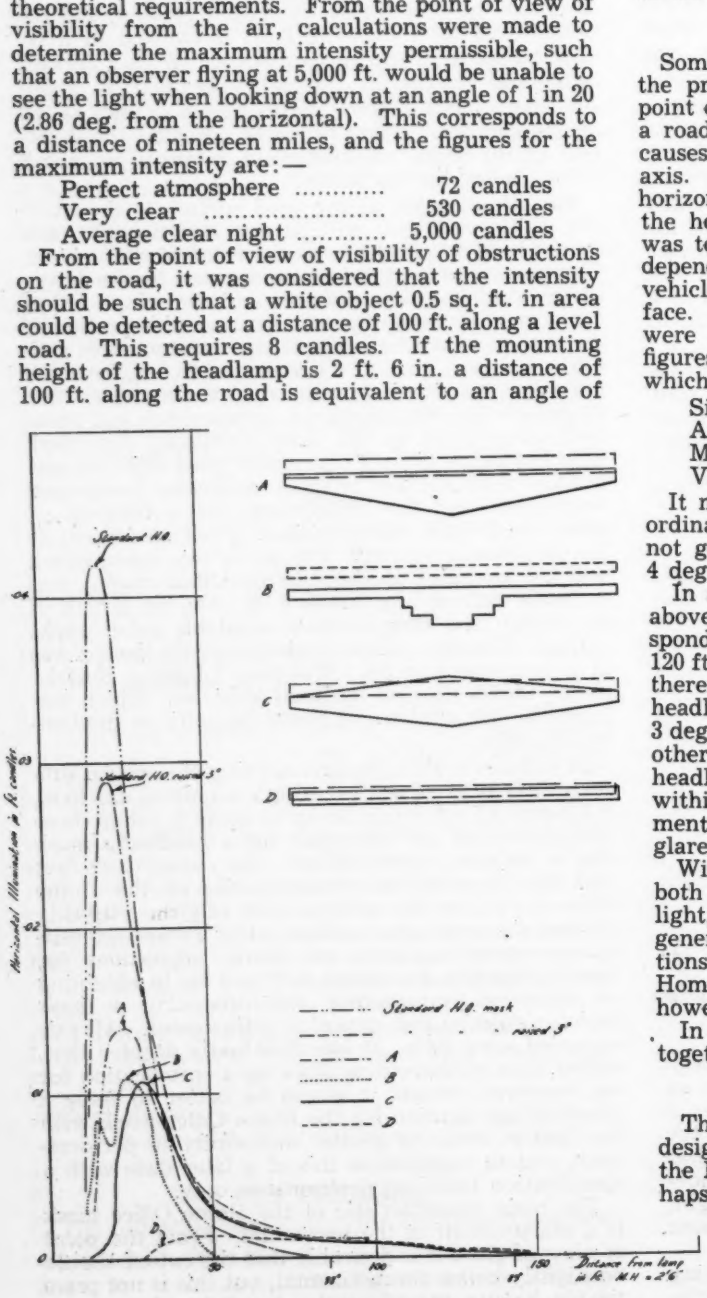


Fig. 2. Showing various slot designs for headlamp masks, and the corresponding distribution of light.

Avoidance of Glare.

Some experiments were carried out to determine the properties of the Home Office mask from the point of view of glare. As the vehicle moves along a road there is a certain amount of pitching which causes the headlamp to rotate about the horizontal axis. Light which is normally emitted below the horizontal may therefore sometimes be directed above the horizontal, and the object of the investigation was to ascertain the amount of this rotation. This depends largely upon the construction of the vehicle and upon its loading for any given road surface. Extensive tests were not possible, but tests were made with four vehicles and the following figures were obtained for the half-angle through which the lamps rotated:—

Singer 9 Saloon	2 deg.
Austin 7 Tourer	2½ deg.
Morris 10 cwt. Van	3 deg.
Vauxhall 12 Saloon	3½ deg.

It may be concluded from these figures that in ordinary circumstances the pitching of a vehicle will not generally raise the headlamp beam more than 4 deg.

In a private car the driver's eyes are about 2 ft. above the level of the headlamps, and this corresponds to an angle of about 1 deg. at a distance of 120 ft. With two such cars on a bumpy road it would therefore be possible for light from the approaching headlamp which would normally be emitted up to 3 deg. below the horizontal momentarily to reach the other driver's eyes. It is, therefore, clear that in any headlamp as little light as possible should be emitted within 3 deg. below the horizontal, and this requirement is more important from the point of view of glare than of visibility from the air.

With a view to giving a better distribution of light both from the point of view of glare and as a driving light, a number of suggestions were tried out. In general, these suggestions related to slight modifications to the number and shape of the slots in the Home Office mask, the main features of the mask, however, remaining unchanged.

In Fig. 2 various modified slot designs are shown, together with the light distribution in each case.

The Need for a Specification.

There are, obviously, a large number of possible designs, some of which may be an improvement over the Home Office pattern in some respects, but perhaps less satisfactory in others. It would be difficult to select one design from the multitude and to establish this as a standard. A more practical solution would be to draw up a specification defining the performance to be aimed at, thus allowing designers to exercise their ingenuity to the full. The use of masks other than of

the Home Office pattern is, of course, permitted by the Lighting (Restrictions) Order, but when the 1940 Order was issued no other masks were available, and, as has already been stated, the adoption of the Home Office mask was, in effect, compulsory. There has always been a loophole, however, in that any other mask fulfilling the simple performance requirements stated in the Order could be used. The performance requirements as stated in the Order are, however, open to ambiguity in interpretation, and a more detailed performance specification was felt to be very necessary. On the other hand, it was evident that for some time to come the Home Office pattern would continue to be used by the majority of motorists, and this type of mask was being made by several manufacturers. The drawing and description given in the memorandum issued by the Ministry of Home Security were not in themselves adequate to ensure uniformity, and it was, therefore, considered that a more complete specification for the Home Office mask was also a matter of urgency.

The performance of this mask depends upon two main factors, namely, accuracy in working to the dimensions and the properties of the diffuser used behind the slots in the back plate. As regards the dimensions, a new drawing was prepared showing in the minutest detail the tolerances on all the dimensions essential to control the optical characteristics of the mask apart from the diffuser, tolerances on these dimensions also being laid down. As regards the diffusing material, there is an optimum degree of diffusion if we assume that materials giving a symmetrical diffusion to a parallel beam of light will be used. If a material with too great a diffusing power is used, the candle power in the forward direction is substantially reduced, while on the other hand if a weak diffusing material is used a high candle-power in the forward direction will be obtained, but at the expense of beam spread in the horizontal plane.

Properties of the Diffusing Screen.

The properties of three different diffusing materials are shown in Fig. 3. It is evident from this illustration that the candle power in the forward direction and the horizontal spread of the beam depend very largely on the diffusing material used.

From the geometry of the Home Office mask it could be shown that in the vertical plane the diffusing material should produce from a parallel beam a strong component in a direction 6 deg. below the horizontal and that any diffusion beyond 12 deg. below the horizontal is of no value. In the horizontal plane, however, some proportion of the beam should be spread out to, say, 30 deg. on each side of the axis. It therefore looks as though the best results would be obtained from a material having different diffusing properties in the vertical and horizontal planes. A good deal of work has been done with a view to producing diffusing material for masks having an asymmetrical distribution of this sort, but up to the present the attention of the Committee has been directed mainly to the more common materials having symmetrical diffusing properties. Beyond drawing attention to the fact, therefore, that future developments may be in the direction of asymmetrical diffusers, we will here confine our attention to symmetrical diffusers.

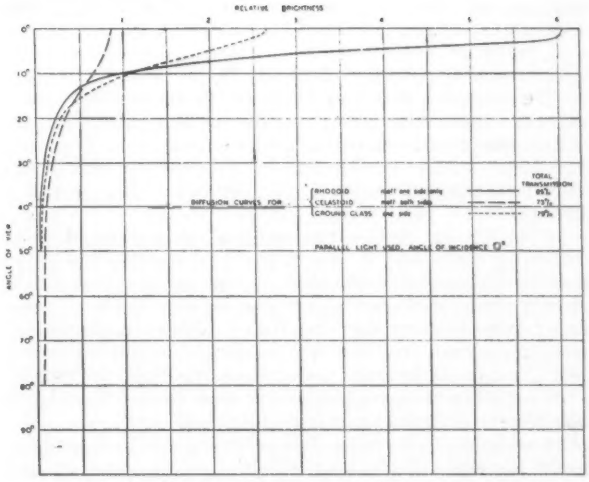


Fig. 3. Showing diffusion curves for various materials. (Rhodoid, Celastoid, and Ground Glass).

The distribution of light from an unmasked headlamp shows a fairly sharp cut-off at the top and bottom of the beam, the peak candle-power being of the order of 100,000 candles, and the spread of the beam extends to perhaps 5 deg. or 6 deg. on each side of the axis. If a Home Office mask, without any diffusing screen, is placed in front of a headlamp no appreciable amount of light can get through along the axis. At 1 deg. below the horizontal a narrow strip of the headlamp reflector is visible through each front slit, but although the candle-power from the reflector is still of the order of 50,000 candles in that direction the smallness of the exposed area results in a candle-power in that direction from the mask of only about 1,500.

As the mask is viewed at increasing angles below the horizontal the area of the reflector visible through the front slots increases, but the candle-power from the reflector rapidly decreases. In fact, the maximum candle-power is emitted at an angle of 1 deg. or 2 deg. below the horizontal, and there is sensibly no light beyond 10 deg. below the horizontal.

If, however, the back slots are covered with a diffusing material the beam of maximum intensity is lowered, and with a completely diffusing material the maximum beam is at an angle of 6 deg. below the horizontal, this being the angle at which the whole area of the back slits is visible through the front of the mask.

The more completely diffusing the material the smaller the total light output from the mask. On the other hand, the more completely diffusing the material the greater the sideways spread of the beam.

The optical properties of the diffusing material are therefore a governing factor in the performance of the mask, and if a specification is to be tied up with the dimensions of the Home Office (or any other)

pattern of mask, the properties of the diffusing material must be closely defined. With a good diffusing material variations in focussing position of the filament, irregularity in the reflector and variations in the relative position of the slits have only small effects upon the final candle-power distribution. When there is little diffusion the reverse is true, and the disparities in performance between one headlamp combination and another become increasingly greater.

In order to define the optical characteristics of diffusing materials it is sufficient to specify the relative brightness distribution curve using parallel incident light, and the light transmission factor. In the draft specification for the Home Office mask which was prepared by the I.E.S. Sub-Committee some months ago, but never published, the light transmission factor was specified as not less than 0.7 and the brightness diffusion curve was also defined.

In addition to its optical characteristics the material must possess satisfactory mechanical properties and must be able to withstand the effects of heat and moisture. The motorist might desire to clean the diffusing material, which must therefore be able to withstand a certain amount of rubbing. Its mechanical and physical properties are therefore important, and it was found that with some materials wiping with a damp or oily cloth would very materially alter the optical characteristics of the mask.

Plastic Diffusers.

It is known that glass is a satisfactory material for use in headlamp masks, but some doubts were felt regarding the ability of plastic materials to withstand the high temperatures involved. An investigation into the properties of plastic diffusers was therefore made, and the first step was to determine the temperatures actually encountered in a masked headlamp. The test conditions were severe, as it was desired to ascertain the highest temperature ever likely to be encountered in practice. The samples tested were in the form of discs about 6 in. in diameter, fitted to a standard Home Office mask with a 48-watt lamp, which was run for one hour at 14 volts. The temperature at various points on the disc was determined by the use of temperature-detecting paint, small blobs of which were placed at intervals over the surface of the disc. This paint is pink at a temperature up to 145 deg. F., and then as the temperature increases the colour changes successively to mauve, white, yellow and buff. It was found that in general the thicker the material the higher the maximum temperature. Certain samples suffered rather badly.

Fig. 4 shows the effect of heat on one material which was used in a headlamp mask. After two hours the material developed clear patches, with the result shown on the curve, which shows the distribution of light from a masked headlamp, in a vertical plane, in the forward direction.

The opinion was expressed by manufacturers of plastic materials that satisfactory materials to withstand these high temperature conditions could be produced. With a view to the development of such materials a method of test was evolved combining both temperature and moisture effects, and manufacturers were asked to submit samples of materials for test. Unfortunately, however, so few samples were sent in that no independent laboratory felt justified

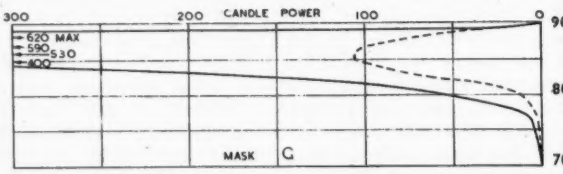


Fig. 4. The full line graph and figures show the results after the mask had been in use for 2 hours. Initial values are shown on the dotted curve.

in spending the time on carrying out the tests. It is possible, however, that the plastics manufacturers are themselves carrying out tests along the lines agreed upon. In the meantime, we know that glass will stand up to practical conditions, and in the specification BS/ARP 36 it states that any diffusing material used must, for the time being, be glass. As soon as it is possible to issue a specification for satisfactory plastic materials such materials will be permitted.

Specification for Performance of Masked Headlamps

It has already been mentioned that the draft specification for the Home Office pattern of mask was never issued. There were various reasons for this which need not be discussed here, and it was eventually decided to concentrate on the issue of a specification defining the performance required of any mask for it to comply with the Lighting (Restrictions) Order. This specification has now been issued as BS/ARP 36.

The two essentials of any performance specification are the method of testing and the values to be assigned to the essential characteristics when measured in accordance with the prescribed test method. In the case of a headlamp mask the most important factor in the method of test is the voltage at which the illumination values are to be measured. This immediately raises the question—what is the voltage across the lamp when the engine is running? In the case of a car fitted with a 12-volt battery, is the voltage across the lamp normally 12 volts or something higher than this? Data on this point is somewhat difficult to obtain, as the voltage depends upon such factors as the mechanical and chemical state of the battery; the temperature of the battery; the charging rate in relation to lamp load and the voltage-drop in the wiring. Some of these factors may work in opposite directions, but on the whole it seems likely that when a car is travelling at high speed the voltage across the lamp will be in excess of the rated voltage. Consequently, if a mask just complies with the Order when tests are carried out at the rated voltage, slightly too much light may be obtained from the mask when the car is travelling at high speed. On the other hand, if tests were made at, say, 13.5 volts instead of 12 volts and the specification were based on such measurements, the motorist

would obtain less light than he was entitled to when travelling at slow speeds, as he would do in a "built-up" area.

Taking all things into consideration the Committee decided that tests should be made with the mask fitted to a standard headlamp, the voltage across the lamp being as closely as possible equal to the rated voltage. This means that with a brand new headlamp and bulb the mask might give slightly too much light when the car is running at high speed, but in practice this would be discounted by the fact that the condition of the reflector and bulb would not, in most cases, be perfect.

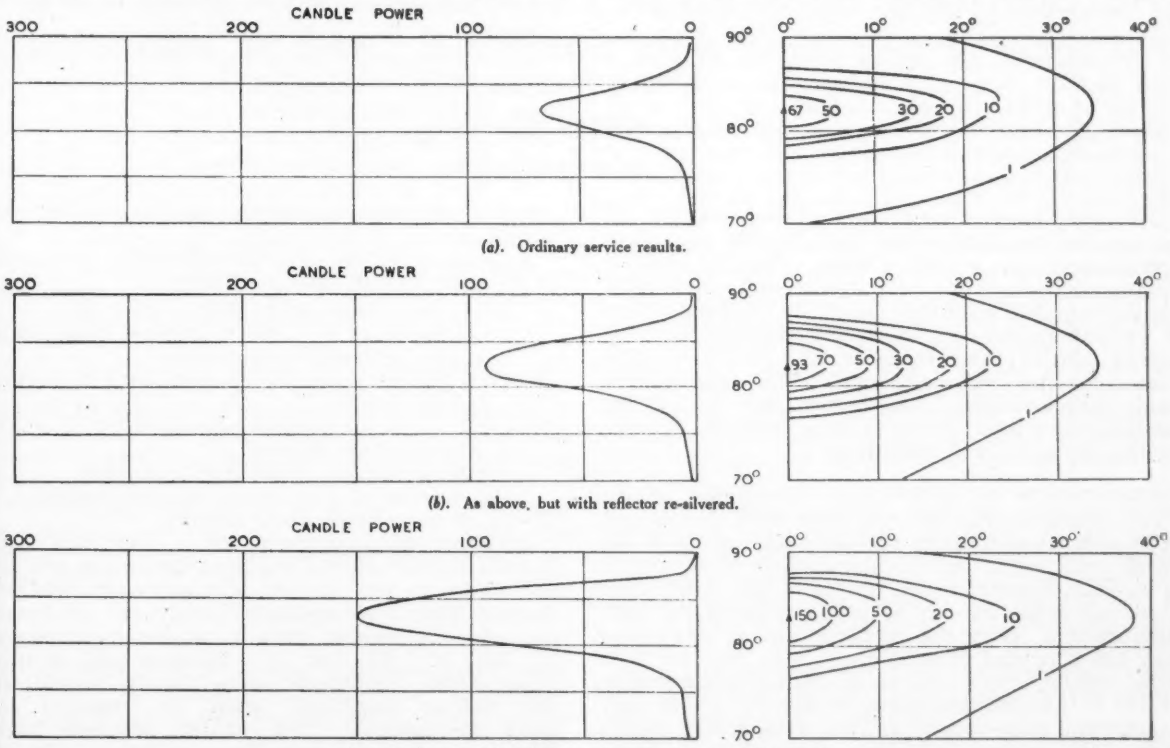
Fig. 5 shows the effect of renovation of a headlamp after it has been in service. It should be emphasised that in its original condition the reflector of this headlamp was very poor, and consequently the effect of resilvering is greater than would otherwise be the case.

With regard to the illumination values to be specified, these were designed to secure compliance with the Lighting (Restrictions) Order, and at the same time to ensure that a reasonable amount of light would be obtained. The Order only stipulates the maximum; it is therefore possible that, as no minimum is specified, a mask might comply with the regulations and yet be totally inadequate from the motorist's point of view.

The illumination values provisionally decided upon are shown in Table I. Tests on a number of commercial masks were then made at the N.P.L. and these tests confirmed that the specification could be complied with by the Home Office pattern if the dimensions are adhered to with reasonable manufacturing accuracy, and if the diffusing material used is equivalent to frosted glass of medium coarseness. The tests also showed that adherence to the requirements relating to stray light intensities outside the main beam (i.e., above the horizontal and below 12 deg. below the horizontal) is greatly facilitated by the use of a matt black internal finish.

The specification requires that the rated voltage and wattage of the lamp with which the mask is intended to be used must be marked on the mask. This means that the designer may, if he so desires, design a special mask to suit particular lamp ratings. The effect of using different lamps is shown in Fig. 6. There is no substantial difference between the two types of 36-watt lamp, but there is an appreciable difference between the 24 and 36-watt lamps. From tests made at the N.P.L. it can be concluded that it is possible in theory to construct a mask of the Home Office pattern which will satisfy the illumination limits given in BS/ARP 36 whether it is used with a 24-watt or a 36-watt lamp; but, as already indicated, a manufacturer might prefer to produce separate masks for these two wattages.

Some of the curves obtained by the N.P.L. were



(a). Ordinary service results.

(b). As above, but with reflector re-silvered.

(c). As before, but with reflector re-silvered and a new bulb inserted.

Fig. 5. Performance of standard mask used with headlamp fitted with 36-watt bulb, showing effect of re-silvering and insertion of new bulb.

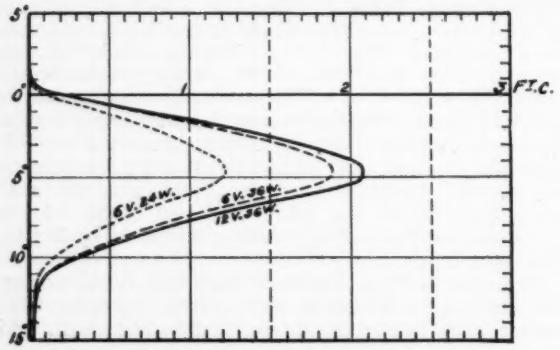


Fig. 6. Polar curve in vertical median plane of a typical mask.

shown at the meeting. They were all taken with a 12-volt 36-watt bulb. In these curves dotted vertical lines represented the limits between 1.5 and 2.5 ft.c. The lower limit of 1.5 was eventually reduced to 1.25, thus making it easier for one and the same mask to comply with the specification when fitted with either a 24 or 36-watt bulb. With a view to eliminating variations in test results due to the use of lamps having slightly different efficiencies, all test figures were corrected to correspond to a standard lamp of known efficiency when used in a standard headlamp. In practice this is done by measuring the total lumens emitted by the test headlamp with the mask removed. Let this be x. The illumination values, as measured with the mask in position, are then multiplied by a factor equal to $\frac{x}{y}$ where y represents the standard total lumens as obtained with a standard bulb in a standard headlamp. The values of y for the various bulb ratings are given in the specification.

TABLE I.
Light Distribution from Standard (BS/ARP 36) Headlamp Mask.

Angle of emission.	Illumination at 10 ft. (foot-candles).
Any angle	Max. 2.5
Angle of max. emission	Min. 1.25
1 deg. above horizontal	Max. 0.01
5 deg. ,, ,,	,, 0.001
12 deg. below horizontal	,, 0.1
20 deg. ,, ,,	,, 0.02

Spread. Within 20 deg. of either side of forward direction the illumination shall be not less than 1/12th of the maximum.

THE LIGHTING OF SHELTER ENTRANCES AND A.R.P. SIGNS

A RESUMÉ OF SOME OF THE WORK CARRIED OUT DURING THE PREPARATION OF BS/ARP 32

By J. BERTRAM *(Member)*

(Paper read on March 11, 1941)

This short paper reviews some of the work that lay behind the preparation of the British Standards Specification on A.R.P. signs, No BS/ARP32. Mention is made of the work carried out in determining the required brightness levels, in the preparation of various optical designs, in the standardisation of legend, and of the method of test by which signs would receive their approval. The development work here described was carried out in various laboratories whose members were actively engaged on the I.E.S./A.R.P. Committees.

DETERMINATION OF APPROPRIATE BRIGHTNESS LEVEL.

It is fitting first to refer to some work carried out at Watson House under the direction of Mr. F .C. Smith with regard to the illumination of entrances to air-raid shelters, as the results of this work were of considerable use in the preparation of the sign specification. Here the problem was to determine how the surround of a doorway, 6 ft. high by 3 ft. wide, should be treated to be readily recognisable at 100 ft. but inconspicuous at 250 ft. (Note that exactly the same condition applies to A.R.P. signs.) Before the final results were obtained tests were undertaken for both field and controlled laboratory conditions. Time does not allow of a detailed description of these experiments, but briefly they were as follows.

A series of lantern slide transparencies were made of the shelter door when outlined by

(1) A continuous white line 1 in. wide.
(2) A series of 1 in. white squares separated by 4 in. between their centres.
(3) 1 in. white squares separated by 7 in. between their centres.
(4) 1 in. white squares separated by 13 in. between their centres.
(5) A continuous white line 2 in. wide.
(6) A series of 2 in. white squares separated by 7 in. between their centres.

All these markings were on a very dark background and extended along both uprights of the door and across the top. In both laboratory and field tests lantern slides were projected singly and the brightness of each lowered until it became inconspicuous at 250 ft. At 100 ft. distances all outlines under these conditions were clearly visible and the coarser markings could be resolved into their components. The values obtained naturally varied very considerably from slide to slide, because as the brightness was lowered, it became impossible to resolve some of the broken

lines into their individual components even at 100 ft. although the main outline was still readily visible at that distance. The 1 in. continuous line was therefore taken as a standard of comparison and set so as to be not conspicuous at 250 ft. The other slides were then projected alongside and their brightness adjusted until they appeared of equal conspicuity. This determined the order of brightness which would be required and also showed which types of marking would be of greatest advantage.

In the second part of this investigation experiments were carried out to determine the period which must elapse before the eye, when adapted to a brightness level equivalent to a well-lit room, could recognise the dimly lit outline of the shelter entrance upon extinction of the conditioning illumination. Again, tests were taken both in the laboratory and in the field, and the effect of seeing the marking against a background of measurable brightness was also investigated, because full moonlight would give a background of considerable brightness under normal weather conditions.

The result of all this work showed that—

(1) When individual details of the marking around the door cannot be picked out by the eye, there is a limiting integrated brightness independent of the pattern which is just not conspicuous at 250 ft.

(2) In the adaptation experiments there was no appreciable difference in time before any of the markings of equal conspicuity became visible. Where the pattern could be resolved broken lines, especially with small gaps, were very distinctive, but a higher brightness was required in this case, thus causing trouble from spilled light.

(3) There is a very great difference in the adaptation time of different observers.

The conclusion was therefore drawn that with a completely dark background and with the observer dark adapted, a 1 in. continuous line of 0.003 e.f.c. (equivalent foot-candles) would satisfy the requirement. To allow for the effect of background this should be multiplied by 5, giving 0.015 e.f.c. The adaptation experiment showed that if this value was raised to about 0.50 e.f.c. there appeared a reasonable chance of everyone seeing the outline in a very few minutes.

Bearing this work in mind when the committee investigated the visibility of the A.R.P. signs, an average brightness of 0.04 to 0.1 e.f.c. was found to be satisfactory.

Legends.

With regard to the legends which appear on the signs, it is obvious that if the full description of each of the premises concerned was given on the sign and the sign made visible from a reasonable distance, say, 100 ft., then the lettering and therefore the sign itself would have to be of very large proportions. In view of this, it was felt that symbols such as those used for traffic signs should be adopted, and the full wording added underneath purely for educational purposes. The passer-by in daytime would spot the symbol in the distance, wonder what it meant, and then as he came closer would be able to read the full legend, thus gradually educating himself to recognise automatically the symbol at night.

In the case of the direction sign it was decided to employ an arrow to indicate the direction in which the premises to be located lay. Now the normal procedure in traffic signs to indicate to a person observing them to proceed ahead, is to have the arrow vertical with the barb pointing upwards. It was felt, however, that the general public might thus be misled, and that the arrow would have to be horizontal with the barb pointing in the appropriate direction. You can well understand that whereas there would be no confusion regarding the direction of a road, an arrow pointing upwards might cause some confusion in certain minds when in front of a many-storied building. This decision meant that these signs would have to be located with the illuminated face parallel to the curb line.

The standard printing recommended in the Ministry of Transport Departmental Committee Report on traffic signs has been adopted, and the table given in Appendix B of the specification has been taken en bloc from this report. The barb of the arrow also has been adopted, and experiments showed that for the conditions required a tapering tail, as recommended in the M.O.T. Report was unnecessary. To ensure optimum visibility some subjective tests were carried out to determine the best length of tail and the distance separating the arrow from the legend. You will note that on all direction signs the arrow is towards the side of the sign nearest to the location, and in all except one it follows centrally from the symbol. The exception is the "Police" sign; here the arrow is above the word, but it is not centrally placed. It also is offset in the direction intended.

The reason is partly psychological, for at maximum viewing distance, concomitant with the requirements of conspicuity, the arrow barb is visible only to people with first-class vision. To those not so well blessed there only appears a line, but the fact of its directional offset helps to indicate the direction intended, thus minimising any hesitation or confusion which might arise before close-up confirmation was obtained.

With the data available from the work on shelter entrances, some further subjective experimental work in the laboratory quickly established the size of legend and the range of brightness mentioned above. You all know that the signs are 2 ft. by 1 ft., and that the average brightness lies between 0.04 and 0.1 e.f.c. This brightness range will allow fairly quick perception to eyes adapted to indoor lighting when switched suddenly to conditions where there is some background brightness.

In order to avoid confusion with traffic colour codes, and to ensure ease of distant recognition at all times, it was decided to make the colour of all

symbols, arrows, and legends sensibly white, both by day and by night. The reflection factor of these symbols had to be not less than 40 per cent., and the remainder of the sign to be finished in black with no border. At one time it was intended to use the red cross emblem, but it was found that certain Articles in the Geneva Convention stated that this emblem could only be used in wartime for activities under direct military control.

Optical Design of A.R.P. Signs.

Any type of illuminant, electricity, gas, or oil, could be used, and it was obvious that the signs would fall into two categories—externally lit and internally lit. The experimental and development work in connection with this specification had shown that considerable care and accuracy were necessary to obtain the brightness level required, at the same time avoiding spilled light or excessive brightness diversity across the sign, and it was therefore felt desirable to give some guidance on suitable optical designs. These have been given in Appendix B. of the specification,

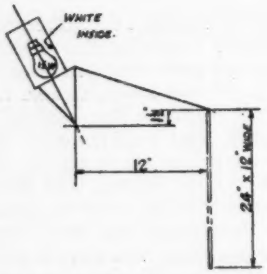


Fig. 1. Externally illuminated sign (electric)

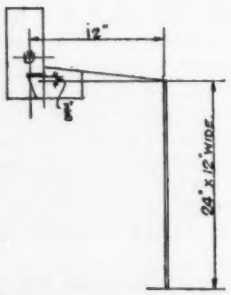


Fig. 2. Externally illuminated sign (gas).

and it is explicitly stated that they do not form part of the specification. You will all be familiar with these designs, but I will just mention one or two special features about the different designs shown.

1. *Externally Lit Sign* (*See Figs.* 1-3).

In both the vertical and horizontal electric signs the illumination is obtained from a very small rectangle of frosted or opal glass placed 12 in. from the side and with a 50-watt lamp behind in a suitable lamp box. To prevent spill light being reflected down from the top shield, which also connected the lamp box to the side, and to cut down specular reflection from the top of the sign, a small light shield has been added as shown. The principle for both the horizontal and vertical signs is the same, only the dimensions being altered slightly.

The principle of the gas sign is exactly the same, a slight modification to the design being required because of the nature of the illuminant. Also note that the opal or ground glass screen is so placed that no downward light is reflected from the top shield.

In the case of the lamp house for a paraffin lamp, specially cut masks are provided to operate with a flat flame burner. These are designed to prevent any spill light and have a clear glass cover over the lamp house to project an image of the flame on to the sign. Note that the height of the flame has got to be controlled.

2. *Internally Lit Sign* (*See Figs.* 4-6).

In the investigational work on this sign it was found that the simplest and, in fact, the ideal way of obtaining even brightness across an opal sheet 2 ft. by 1 ft. was by means of a controlled distribution from a lamp box at each end of the sheet. This can be done by means of a slit projector, giving a long narrow distribution with the maximum beam toward the far end of the sheet. The model on which most of the preliminary work was done is shown on Fig. 4. The final arrangement shown in the specification and on Figs. 5 and 6 for both gas and electric signs is another way of obtaining the same result,

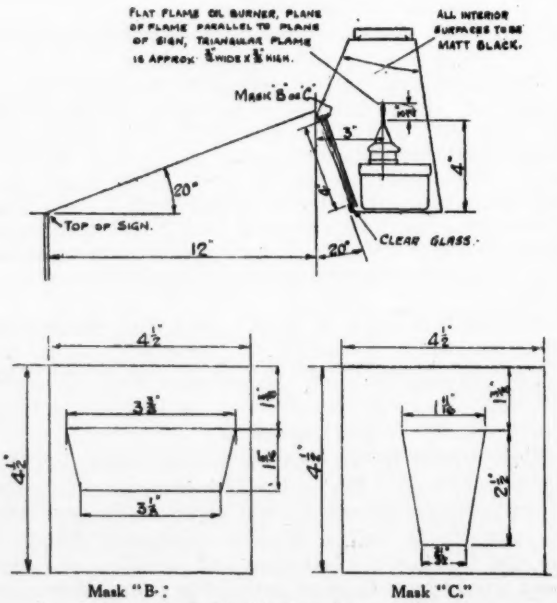


Fig. 3. Externally illuminated sign (oil lamp).

the mirrors at each end reflecting the slit in the centre lamp house.

Approval Tests.

The designs described in the Appendix of the specification will conform with all the requirements of the specification, but as it was expected that other designs would be forthcoming, and also known that the accuracy of these optical designs was dependent upon their mechanical construction, it seemed desirable that there should be some standard method of test to ensure compliance with the specification and to obtain the B.S.I. mark. This has been included in Appendix F, and is intended to cover confirmation with clauses 7, 8, and 9—the Brightness of Symbols and Legends, the Control of Light, and the Screens. A general inspection is also included. It should be noted that an average brightness of between 0.04 and 0.1 e.f.c. is required with a maximum to minimum brightness ratio of 50 : 1, allowed with the proviso that the ratio between adjacent 3-in. squares is not greater than 3 : 1. These figures were obtained after a critical examination of a number of signs considered to be satisfactory. For exterior lit signs illumination measurements are taken at the centre of 3-in. squares, and converted to brightness figures by multiplying by the reflectivity of the sign paint. For interior lit signs plain sheets sprayed to the standard finish but with the black masking omitted has to be provided. This, again, is divided into thirty-six 3-in. squares and the brightness at the centre of each measured. To ensure that no trouble will be obtained from spill light from the exterior of the sign a maximum figure of 0.001 ft.c. has been specified for the illumination allowed at the centre of 3-in. squares just outside the sign. This figure of 0.001 was derived from the figure of 0.00025 ft. c. permitted in street lighting, and on the assumption of a minimum mounting height of 8 ft.

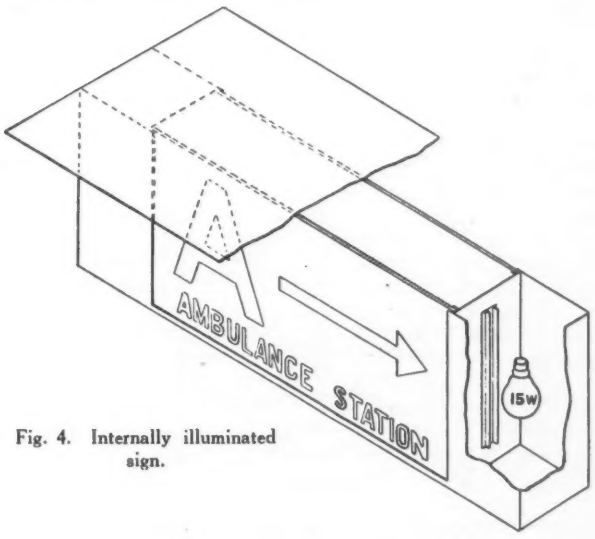


Fig. 4. Internally illuminated sign.

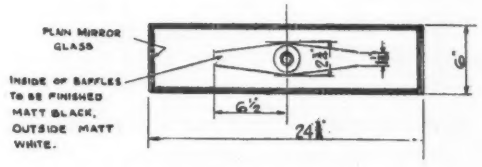


Fig. 5. Electrical Design.

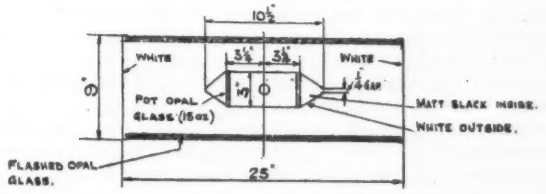


Fig. 6. Gas Design.

METHODS OF PROVIDING LOW VALUES OF ILLUMINATION

(BS/ARP.16, BS/ARP.20 and BS/ARP.21)

By R. MAXTED *(Fellow)*

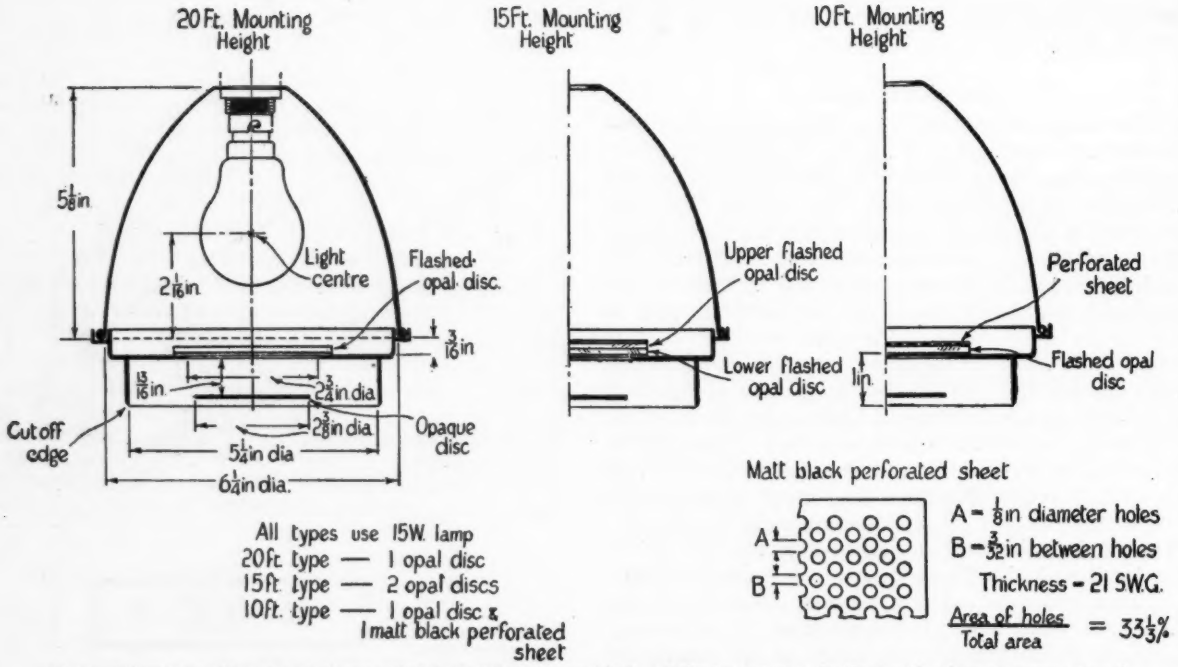
(Paper read on March 11, 1941)

Of the A.R.P. series of B.S. Specifications, those dealing with illuminations of 0.002, 0.02, and 0.2 foot-candles were prepared by I.E.S. members serving in the first place on A.R.P. Sub-Committee No. 1 of the I.E.S. and, secondly, as members of the corresponding Technical Committees of the B.S.I.

The work of Sub-Committee 1 began shortly before the war, and lighting restrictions were enforced just as consideration of the 0.002 ft.c. level was bringing a fuller appreciation of the problems involved in fittings design. There was immediately an urgent demand for the completion of specifications dealing with 0.002 ft.c. and 0.02 ft.c., and a further request for priority to be given to a specification dealing with a level of 0.2 ft.c.

Considerations of expediency, therefore, greatly influenced the form of specification, which consisted not only of mandatory clauses stating conditions which must be fulfilled, but also of further sections describing fittings which were considered to conform. The fittings designs were included for guidance only, and for the primary purpose of assisting in the rapid implementation of the specification.

In thus adopting designs, the Committee had to



Note—All metal surfaces on mask to be finished with 5% matt black. Reflector interior finished with white vitreous enamel.

Fig. 1. Electric Fitting (IES/ARP/0.002) for Close Spacing (2:1) Giving Circular Light Distribution for General Lighting.

take as its objective fittings designs which could be rapidly finalised for inclusion in the specification and which were sufficiently simple for the resources of all potential manufacturers to be employed in production. It is well at this time to recall these earlier requirements because some of the designs are open to criticism when considered only on technical grounds. This was appreciated by the Committee, who nevertheless took the broader view necessary at that time and considered that the designs represented a reasonably optimum result on that basis. It should be noted that nothing in the specification precludes the more leisurely development and manufacture of improved types.

Form of Specification.

In considering the form of specification adopted for illuminations of 0.002, 0.02, and 0.2 ft.c., it is reasonable to draw comparisons with the very different method used in the case of the 0.0002 ft.c. level specified for street lighting. Justification for different treatment is found in the differing conditions of use, security requirements and administrative problems.

In street lighting the statutory limits of illumination are achieved by specifying the photometric performance of the lantern within close limits, and by an equally rigid specification of the correlated installation dimensions permitted. The photometric performance of the lantern is ensured by using the machinery of the B.S.I. Certification Mark. This exacting procedure is fully justifiable on the score of security, since street lighting is primarily intended for use during air raids on nights devoid even of natural starlight, and because under these conditions it will be in use over extensive adjoining areas. From the administrative point of view, the form of BS/ARP.37 is essential in providing a practical means of checking the compliance of an installation, especially having regard to the accuracy required at values of illumination which cannot be readily measured.

With illuminations of 0.002 ft.c. and higher, it is however, practicable to check compliance by measurement on site, having regard to both the greater ease of measurement and the less exacting security requirement when lighting is to be switched out while hostile aircraft are still at a considerable distance. (BS/ARP.30 refers to Gauges for checking low values of illumination—0.001 ft.c. to 0.2ft.c.) It was, therefore, satisfactory to specify the results to be attained, leaving considerable latitude in the methods adopted. It was also considered desirable to leave as much scope as possible for the adaptation of existing fittings, since in certain cases this might be more expedient or more economical than the installation of special fittings. Furthermore, great diversity was anticipated in conditions of use and in the shape of area to be lighted.

BS/ARP.16 and BS/ARP.20.

In the case of Specification BS/ARP.16 and BS/ARP.20 the same general form of specification is adopted. The first clause is explanatory, and Clause 2 is mandatory and specifies the photometric per-

formance of a fitting only in terms of the illumination to be produced at ground level, and of a cut-off at 5° below the horizontal. Clause 2 also deals with screens to prevent the illumination of vertical surfaces or extraneous areas, precautions necessary to ensure proper functioning of conversion units, and with the durability of equipment.

The remaining clauses of the specification then deal with the optical designs of units, both gas and electric, complying with Clause 2, and these parts are mandatory only in relation to fittings bearing the I.E.S./A.R.P. Mark. These clauses also specify mounting heights and spacings to be used with the designs described.

BS/ARP.21.

This specification differs from the other two specifications in two main aspects. First, the fittings are described mainly by reference to the photometric performance of an individual fitting, and the specification sets limits to the shape of the polar curve and specifies the order of the intensity in the direction of the downward vertical. Secondly, the fittings are not required to have a cut-off at 5° below the horizontal, but must emit no light above the horizontal.

In the case of the gas fitting described in the specification, the full optical design is given for a light distribution giving the minimum diversity of illumination at a spacing height ratio of 2:1. In the case of the electrical fitting the general form only of the reflector is illustrated and the specification is framed to permit the use of both specular reflectors and diffuse reflectors. A properly designed specular reflector will, of course, give a low diversity of illumination.

This form of specification was adopted because the level of illumination is such that normal industrial lighting practice can be used in the case of electrical equipment.

Revision of BS/ARP.16.

A revised specification was issued in February, 1941, the principal changes being:—

(a) Addition of fittings designs for a 2:1 spacing height ratio.

(b) Inclusion of appendix— Notes on the use of the lighting fittings."

(c) Details of screen are given.

The fittings for a spacing height ratio of 2:1 were added because experience had shown that in many applications light emitted from the fittings at angles approaching 85° served no useful purpose. This high angle light therefore resulted in unnecessary glare, which was especially noticeable at the lower mounting heights. It will be noted that in the case of the electrical fitting for a 2:1 spacing height ratio, an opal glas disc is used and this acts as a secondary source of low brightness—a feature which is found to be a real advantage at low values of illumination.

The Advantages of Standardised Equipment.

It has been mentioned that the three specifications were framed so that the mandatory clauses could be met by the suitable modification of existing fittings. While it may be desirable to allow this scope in certain cases, it does appear that, in the light of experience, there is much in favour of conversion of installations by the insertion of special fittings such as those described in the specifications.

Thus the use of I.E.S./A.R.P. Mark fittings relieve the user of the difficulty of developing a suitable modification to existing fittings, and assists both the user and the inspector when an installation has to be checked for compliance with the Lighting Restrictions Order. Many of the "simple" methods of adaptation—such as the use of sprayed lamps—show an initial advantage of low cost of conversion, but it is probable that a standard conversion unit would prove more economical over a period of working. In the case of relatively small installations, the difficulty of achieving and maintaining compliance with the Lighting Restrictions Order obviously makes it uneconomic to embark upon the modification of existing fittings when, at a small initial outlay, approved standard fittings can be installed.

The general experience of the working of the specifications dealing with 0.002 ft.c. and 0.02 ft.c. therefore confirms the wisdom of including in the specifications details of approved fittings.

DISCUSSION

Mr. Percy Good (Chairman of the Joint Lighting Committee and Joint Director of the British Standards Institution), discussing some of the work that had been done recently, said that much of it could not be dealt with publicly yet. Some of the committees on which the Society was represented had been investigating the problem of visibility from the air, i.e., ascertaining the distances at which one could see various light values under the different conditions, and the Committees had gone far towards developing a fairly complete theory and practice on that subject. When those responsible for the work were able to present their records to the Society it would be realised that a good deal of very important fundamental work had been done.

In connection with the development of some special branches of their work the Ministry had asked him to arrange for the assistance that members of the Society could give. The Ministry had left him a free hand as to the sources from which to obtain the information needed, and considerable development work had been done by what might be called secret committees. Though the results achieved would not be published, the work had proved of very great value. Mr. Good paid tribute to the way in which members of the Society had responded to the calls made upon them, and said it was of great interest to note that the Society's membership did include those most competent and qualified to deal with the various problems that had arisen.

The limits of the illumination problems in connection with the war, and the assistance which would be required in their solution, had by no means been reached yet, and he believed the authorities would

still require the services of the experts, practically all of whom belonged to the Society.

Finally, he said he was very glad indeed that the Society was taking steps to profit by the information which was being gained from the study of low-intensity lighting, and was reviewing ideas with regard to post-war efforts in order to apply that information to the best advantage.

Mr. F. C. SMITH emphasized that a great deal of work had had to be done to obtain data before it had been possible to issue the various BS/ARP Specifications. These Specifications had to interpret in terms of the familiar units used in illuminating engineering practice the various requirements set out in the Lighting Restrictions Order. It had been felt that an account of some of the work which lay behind the issue of these Specifications would be of interest to the members of the Society.

One was familiar, for instance, with the requirement in the Lighting Order that a sign should not be visible at 250 ft. whilst being clearly seen at 100 ft. This was a rough-and-ready way of saying what was required, but it was not concrete enough, nor did it ensure uniformity and reproducibility. It was clear that work was necessary to establish the order of brightness required to satisfy this official requirement. In saying this the speaker was not criticising the Lighting Restrictions Order, because those who had to administer this Order were not illuminating engineers, and therefore would require guidance as to what was permitted. The fact that the Society had been able to interpret these requirements in terms of standard units so that signs could be produced to a definite specification had been of considerable value in administering the Lighting Restrictions Order.

Mr. Stanley had indicated this afternoon that a great deal of work had been done by the Society to try to secure reproducibility in the motor-car headlamp mask, and, secondly, to endeavour to improve the construction and optics of the mask. As a motorist, the speaker shared the view that a good deal of improvement was possible. He was hopeful that the work would lead to some practical development in this important field.

The Specifications for low intensity fittings and A.R.P. Signs had given rise to one or two problems common to both. For obvious reasons the Committee which had considered these did not wish to lay down that all the fittings and signs should be produced to one common design: that would have been unwise, because probably they would not have arrived at the best design, and it would not have given those with experience of production methods the opportunity to make the best use of their existing machinery for the production of these fittings. It was better to state the general requirements and then to illustrate a type of fitting or sign to comply with these requirements. Whilst it was easy to produce a sign to give uniform brightness by using expensive optical devices, the Committee had realised that the fittings and signs would be purchased in very large numbers. It had therefore to suggest a type of fitting which could be produced at an economic figure, and had in consequence illustrated simple forms of construction to meet these requirements.

The problem of producing low intensity fittings had been approached in two ways. The Gas Industry had adopted a unit of light, surrounded it with a diffusing cylinder and used external masks so shaped and cut as to produce the various types of distribution and intensities required from the one unit—a mere change of the mask allowing the necessary modifications for the various intensities, etc., to be effected. The Industry, rightly or wrongly, had standardised on that method of approach, and he believed that the fittings produced had been reasonably successful. On the other hand, another type of approach had been to put an illuminant inside a box or cylinder and then to do something with the bottom of the open cylinder to produce the required illumination. Both methods had their advantages. As already stated, the advantage of the method adopted by the Gas Industry was that the intensity could be changed by the mere alteration of the masks. These masks, however, had to be made with extreme accuracy, which meant, of course, some degree of expense and difficulty. The advantage of the other method was that it did not pre-suppose such accuracy in dimensions in order to ensure reproducibility. It was probably true, however, that more light had to be produced for any given unit and, in consequence, the effective light issuing from the fitting was a smaller proportion of that generated than was the case in the gas unit. It should be noted, however, that certain electrical units had also used the first method.

At the time the work of the Committee was commenced people up and down the country were adopting all sorts of expedients in order to produce low intensity fittings to satisfy the Home Office requirements. The work had to be done with despatch and they had to improvise, and a great deal of money had been spent in this way. The waste of energy involved in the use of some of these fittings was astounding. It did seem wrong to produce a high lumen output, then to waste a large proportion of light by using some of the devices with which we were all familiar. The Committee had therefore tried to save energy as well as to produce fittings which could be made at a reasonable price and which ensured good reproducibility. He believed that a great measure of success had been achieved, and those responsible for the administration of the Order had appreciated that the production of such fittings had saved them the trouble of "vetting" a large number of types of fitting. Recently it had been necessary to reorganise lighting in gas works so that work could continue during an air raid even if the walls and windows surrounding the plant were blown out. Standard fittings had been adopted for this purpose, and with the co-operation of those responsible for administration it had been possible to reach agreement quickly and to lay down what was and what was not permissible. That was the great advantage in using a standard fitting the performance of which was vouched for since it complied with a well thought out specification.

Finally, Mr. Smith expressed his thanks to Mr.

Bertram for having undertaken at short notice the work in connection with signs.

Colonel K. EDGCUMBE, discussing the cut-off at the bottom of the motor headlamp mask, to prevent light striking the road surface within 10 ft. of the front of the motor-car, said he had gathered from Mr. Stanley that the reason was that it was not necessary for the motorist to see the road within that distance and therefore any light there was wasted. But he had wondered whether the requirement had been introduced to ensure that the reflection from a wet road surface would come off at a very acute angle and not almost vertically. However, presumably this was not the idea, otherwise it would not be permissible for buses to use masks which directed the light down on to the road surface at a very steep angle.

Whilst appreciating that tarnished or dirty reflectors did reduce the efficiency seriously, Colonel Edgcumbe said he had found to his cost that mud and dust which found its way through the slits on to the translucent screen had a still more serious effect. Last winter the intensity of light from his car lamps was reduced to 1 ft.c., or rather less, at 10 ft., but when cleaned the lamp had given an illumination of 2½ ft.c. He believed that now one could buy translucent caps by means of which that trouble was avoided.

Describing a headlight photometer which his firm had produced at the request of the Home Office, Colonel Edgcumbe said that it consisted of a cubical box with a photo-electric cell at the front and an indicating instrument at the top. The difficulty, of course, was not the photometer, but rather the gentlemen who had to use it—for he did not think that illuminating engineering was taught in very great detail to Police Officers even at Hendon! The photometer was held vertically at a distance of 10 ft. from the headlamp, but two questions arise. Firstly, it was not clear from what point on the lamp should one measure the 10 ft.; but he believed it had been agreed that it should be measured from the nearest point, thus giving the motorist the benefit of the doubt. A second point which had arisen in the Courts was whether or not the engine of the car should be running when the illumination was measured and, if so, at what speed. He believed that a policeman had no right to sit in the driver's seat and put his foot on the accelerator while his colleague measured the illumination. One commonsense proposal was that the engine should be run at such a speed that it charged the accumulator. The legal mind, however, held that the culprit must always be given the benefit of the doubt, and he believed it would be found in future that a motorist could object to running the engine at more than "ticking over" speed.

Still another question was how to ensure that the instrument was reading correctly. The illuminating engineer would no doubt suggest that there should be at the police station a box with a lamp inside it, and a voltmeter; the voltmeter would be set at a certain voltage, and one would know that the illumination at the end of the box was so many foot-candles. That appeared to be a simple way out of the difficulty, but it did not appeal to the legal mind. It was feared that the policeman who was giving evidence, not being an illuminating engineer, would soon be tied up in knots by the questions of the defending Counsel. Therefore, it was concluded that the safest course was for the policeman to produce a certificate to the effect that the instrument had been checked fairly recently and found to be all right.

Mr. A. CUNNINGTON made some reference to the usefulness of the low-illumination gauge now available for measuring (or at least checking) the special values of illumination specified in the Lighting Restriction Order.

He agreed that there was something in the point made by Mr. Maxted that difficulties might arise if there were a widespread use of fittings other than the standard for low-intensity illuminations. Certainly there had been difficulties in regard to guaranteeing the illumination, and also in satisfying the Police. From that point of view it had been found advantageous in some cases to use the standard fittings. But frequently a user who had a large installation or many installations would be very glad to be able to convert his existing fittings in some simple way rather than to replace them with the standard fittings. and Mr. Cunnington did not think there was any serious objection to that.

Challenging the suggestion that a sprayed lamp created difficulties in use (the difficulties being due, presumably, to the irregularity or lack of uniformity), he said he believed the B.S.I. Committee had rather strongly emphasised the evenness of the illumination provided. In his view the important consideration was not the evenness of the illumination, but the necessity to ensure that the legal maximum was not exceeded; it did not matter much if there was considerable variation. If the Committee had not been so much concerned with securing evenness of illumination, they might have felt themselves free to adopt fittings of a far different pattern. Could there be any real objection to replacing a 60-watt lamp in an ordinary reflector by a sprayed 15-watt or 5-watt lamp, the spraying being such that the illumination provided was comfortably below the maximum of .002 foot-candles at any point? By using a sprayed lamp one could overcome entirely the drawback of having a rather high intensity of light passing through a narrow slit.

Mr. A. CUNNINGTON (*communicated*): Any uninitiated person listening to the discussion might get the impression that the alternative fittings adopted by some of the Railway Companies were an inferior makeshift, and that the Railways were at fault in not going in for wholesale adoption of the B.S. fitting. I would like to point out that the facts are entirely otherwise.

For a wide spacing the use of vitreous enamelled reflectors of the inverted dish type with screened lamps gives a light effect altogether superior to that of the B.S. fitting—and for a very simple reason, viz., that they rely on the low illumination of a comparatively large surface as the source of light.

This undoubtedly is what should be aimed at, and I am glad to note that the Joint Committee has apparently come to the same conclusion, judging by the modification made in the revised design of fitting for 2 to 1 spacing.

The only difficulty that has occurred in the alternative fitting is in obtaining a uniform quality of low candle-power lamp. The original blue-sprayed 15-watt lamps were fairly consistent, but since the War the Lamp Manufacturers have not been able to provide such consistency in the spraying of the lamps. The Railway Companies have, however, substituted a suitable grey heat-resisting paint, into which the ordinary lamps can be dipped.

It is, of course, now well known that there is no particular significance in the *blue lamp*, but I am quite at a loss to know why it has come to be a subject of ridicule at the Society's meetings. Blue dye seems to me no better and no worse than green or grey or silica, so long as it reduces the candle-power. If the Lamp Manufacturers can produce a lamp of sufficiently low candle-power to dispense with the coating so much the better.

Mr. E. B. SAWYER, who urged that the situation should be regarded not only from the point of view of safety from the air, but also the point of view of the persons using the various areas, said that the danger of uneven illumination was quite obvious and, further, there was the psychological effect of blue light. The blue lighting in railway trains during black-out hours, when the white lights had been switched off, was quite depressing, as shown by the fact that passengers chose the carriages fitted with the lighter blue bulbs. One of the problems of colour spraying was that it did not ensure anything like uniformity, which raised the question as to whether one should provide the maximum permissible illumination for the benefit of the user, or should take the view that so long as the illumination provided was well below the permissible standard it did not really matter whether or not it was of any use.

As to the adaptation of existing fittings instead of the use of standard fittings, he pointed out that if lamps were treated with a colour which absorbed a lot of light, the temperature was raised and the life reduced. Relatively few early failures were sufficient to offset any saving which might be effected by adapting fittings. A further point was that the additional work involved in spraying made it difficult for the lamp manufacturers to concentrate on the very much more important task of providing the necessary lamps for industry, and to that extent retarded the war effort.

Mr. CUNNINGTON interposed to point out that he had not advocated blue-sprayed lamps; there were other permanent colours which would withstand heat much better than the blue sprays.

Mr. T. J. SACK congratulated the Headlamp Mask Committee on the work they had devoted to the task of drawing up the specification, and expressed regret that so much labour had brought forth so difficult a child. To emphasise his suggestion that the specification was rather obscure on some points, and that it was necessary to read it several times before one could understand it, he quoted the following paragraph from Section 3, dealing with the photometric performance of the mask:—

> "In a plane containing the direction of maximum emission and the horizontal directions at right angles to the axis of the headlamp, the illumination within an angle of 20 deg. at either side of the forward direction shall be not less than one-twelfth of the maximum illumination."—(B.S./A.R.P 36).

It seemed to him also, he said, that the effectiveness of the specification was nullified by the absence of limits of voltage. It was not sufficient, in a scientific publication, to state that the voltage must be adjusted as closely as possible, bearing in mind that a variation of only 2 per cent. made a considerable difference to the illumination given by the lamp. Further, he could not see the force of marking the voltage on the masks, because surely the wattage was the only factor that mattered. It meant that dealers would have to stock two types of mask, i.e., 6 and 12 volt masks, merely because of the markings on the masks, in spite of the fact that in other respects they are identical. The specification could be simplified by adopting the American method, using a target diagram, showing the foot-candlepower values at various points.

Mr. L. E. BUCKELL asked the authors of the papers whether the committee who prepared the specifications had come to any conclusion either for or against the use of coloured or sprayed lamps used with ordinary reflectors to obtain the low levels of illumination desired.

At the beginning of the war, when people were in a great hurry to reduce illumination and when no specifications or fittings made up to specifications existed, a custom started of reducing illumination by the use of colour sprayed or natural coloured glass lamps, particularly blue.

This seemed broadly an undesirable way of attaining low illumination, because there was not and could not be any workable specification covering the actual light output of sprayed or natural coloured lamps owing to the tremendous and unavoidable variation in the absorption of the sprayed or coloured bulb, which even under the most carefully controlled conditions might amount to 200 per cent. or 300 per cent. Some 85 per cent. or 90 per cent. of the total light output was absorbed, and it would be readily seen, therefore, that a reduction in the absorption of only 10 per cent. would result in a 100 per cent. increase in the light emitted.

The supply of these sprayed and coloured bulbs entailed great difficulties at lamp works, because practically every user wanted a different lamp or a different colour or different density of spray; this reducing lamp production at a time when the increased demands for lamps necessitated an expansion in production.

It was suggested that those who at the beginning

of the war started to get their low illuminations by use of sprayed or coloured bulb lamps should reconsider the position. Fittings which complied with the BS/ARP Specifications were now available, and the cost of these did not seem to exceed the cost of three or four lamps. It might easily be that much more saving in lamps than this would be achieved by using the normal 15-W. pearl lamp specified, because, as is well known, spraying or colouring a bulb involves increasing the temperature of the bulb due to the absorption of radiant heat, and this overheating is likely to result in gases being given off which will bring about early failures.

It is understood also that blue in particular is not looked upon as a suitable colour for A.R.P. work. It is hoped, therefore, that those who commenced using sprayed or coloured lamps at the beginning of the war, when nothing better was available, will now reconsider the matter in view of the fact that:—

(1) It is more economic to instal proper fittings in accordance with the BS/ARP Specifications.

(2) The light obtained is unlikely to comply closely with the statutory amount, and may vary so much as to result in individual users being fined for contravening the regulation.

(3) The production of sprayed and coloured lamps, involving an extra process, is undesirable under present conditions, when increased production is required from existing lamp works.

Mr. A. R. McGibbon after criticising the construction of most BS/ARP 16 Fittings recalled that early in the war period he had installed both the gas and electric versions at a mounting height of 10 ft. and spaced at 30-40 ft. They produced a very even distribution of illumination and so complied with the requirements of the specification very well. At the same time, he pointed out that even illumination did not necessarily enable a person to see comfortably; and when he had used sprayed lamps in converted fittings it was agreed by those who had made the comparison that they could see very much better under the converted fittings using sprayed lamps than under the special A.R.P. equipment, because they were not blinded by glare. When walking under the B.S.I. fittings one needed to shield the eyes from glare. The glare was not so noticeable when the fittings were used at 20 ft. mounting height, and where this was possible a number of the B.S.I. fittings had been employed with some success. As the result of these tests sprayed lamps were retained at the lower mountings. It was difficult, sometimes, to obtain sprayed lamps which would withstand the conditions. The possibility of early failure of the spray or filament can be minimised by purchasing ordinary pearl lamps and dipping them, and then under-running the lamps, as efficiency did not matter. These grey dipped lamps stood up very well, the "dip" outlasting the life of the lamp.

Finally, he asked Mr. Stanley what was the maximum level of illumination produced on the ground in front of a car when employing the H.O. Headlamp mask as described by him.

Mr. J. S. Dow presented a photograph, showing the illumination of time tables at Paddington Station, which Captain Robert R. Hoare had submitted as an instance of the possibility of getting a very clear effect with a very low illumination.

He also expressed regret that Mr. E. W. Murray, who was lecturing elsewhere, had been unable to attend to give his views in regard to fittings for low illumination. Mr. Murray, he thought, would contend that at the very low order of illumination involved the present designs gave rise to a substantial amount of glare. It had been urged that it was hardly possible to avoid glare completely if moderately even illumination from widely spaced units was desired. It might well be suggested, therefore, that at these low illuminations one should aim at fairly close spacing. But if wide spacing could not be avoided did it after all matter so very much if the illumination was not very uniform, or even if it reached zero in places provided the change was gradual and there was no abrupt transition from brightness to complete obscurity? If such a sacrifice was necessary in order to eliminate glare completely it might prove worth while.

In conclusion, Mr. Dow asked Col. Edgcumbe whether the type of instrument which he had exhibited was actually being used in large numbers by the Police? If so, it was certainly a triumph for photometry. Referring to calibration problems, he mentioned one County Borough which utilised a species of "standard box," kept on the premises and occasionally tested at the N.P.L., in order to check their photometers.

Mr. F. C. Smith, dealing with the question as to why the Committee had included in the Specification types of fittings which would meet the requirements, said that the Committee was aware that all sorts of expedients were being adopted throughout the country in order to meet the requirements of the Lighting Order. There was no control in regard to these expedients. The Committee could have tackled the problem from the standpoint of prescribing attachments which could be used for various well-known fittings in common use. This aspect was considered most carefully, but it was found that the number of types of fitting in use was so great as to make this a practical impossibility. Rather than make the problem more difficult by trying to deal with every single fitting ever put on the market, the Committee decided that it would be better to try and group the great majority of fittings into five or six different classes and to design a unit which could be attached to each on standard lines. Even this, however, was found impossible as the solution since the number of designs in use was so great. Looked at from one point of view, the gas unit was a conversion unit, since it was necessary to retain the superstructure of the lamp in order to ensure the necessary ventilating qualities. Finally, however, the Committee had designed a

cheap standard fitting, and he believed they were right in so doing. Mr. Smith also emphasised that fittings had been adapted by painting, etc. These required a lot of maintenance if they were to be kept in proper condition. He had seen some appalling examples of the results of neglect, probably due to the fact that there was insufficient labour available for that type of work during war time. Moreover, the expenditure of energy was often far greater than was necessary to give the light output required, and this was quite a serious matter. On the other hand, he emphasised that the Specification set out the requirements, and if a qualified illuminating engineer had units already in service which could be converted cheaply to satisfy the requirements, there was no reason why this should not be done. He believed, however, that a great many people had found it less expensive and more satisfactory to install standard fittings.

Mr. J. F. STANLEY, replying to Colonel Edgcumbe's comment on the visibility of light of a certain candlepower at distances as great as 19 miles, said that in mentioning that figure he was referring to the direct light of the maximum beam; if a headlamp mask were properly adjusted, no direct light would be emitted at angles above the horizontal. However, perhaps due to incorrect adjustment or to oscillation of the headlight as the car moved along the road, a direct beam might be emitted slightly upwards, and that was why he had referred to observation downwards, from a height of about 5,000 ft. at an angle of about 3 deg. That was the only circumstance in which an airman could see a direct beam from a headlight. Observations had shown that visibility from the air was not increased by the road being wet; in fact the patch of light on the ground was less visible in wet weather than in dry.

Referring to comments on the spread of the beam and the wording of the paragraph dealing with it in the specification, Mr. Stanley said the Committee would welcome a simpler wording; he had spent quite a long time with another member of the Committee in arriving at that wording which, though somewhat involved, was technically correct. The real point was, however, that the specification of the performance of the mask was intended for those who were testing the mask in the laboratory, and not to enable a policeman to test its performance on the road.

Finally, he said he would reply in writing to other points that had been raised.

Mr. STANLEY (*communicated*): Mr. Sack queried the necessity for marking the voltage as well as the wattage on the mask. It will be seen from Fig. 5 of my paper that the voltage does affect the light output, though admittedly not so greatly as the wattage. There seems to be no objection to the mask being marked "6 V. or 12 V." provided the manufacturer has satisfied himself that the necessary performance is in fact obtained with lamps of either voltage.

In reply to Mr. McGibbon, the maximum level of illumination produced on the ground in front of a car when using the Home Office mask is of the order of 0.05 ft.c. The area illuminated at this level is, of course, very small, as may be judged from Fig. 1 of my paper.

Mr. R. E. MAXTED, in reply to the discussion, said that Mr. Cunnington's remarks really raised two separate issues.

With regard to the use of sprayed lamps, Mr. Cunnington had referred to the case of the large organisation having the services of a competent lighting engineer. In this case the use of sprayed lamps could be quite satisfactory provided that a suitable sprayed lamp were available and that such a lamp could be economically manufactured to the required tolerances—and of course others taking part in the discussion have referred to the economics of lamp production. In the case of the large organisation the cost to the organisation of devising a special means of conversion could be relatively small if the existing reflectors and installations were not of too diverse a nature. The real difficulty with sprayed lamps seemed to be their promiscuous use in small installations. In Mr. Maxted's experience it appears that many users were under the impression that they had merely to order sprayed lamps to give 0.002 ft.c. and that these lamps when fitted in any reflector would under any circumstances give the required illumination. The opinion seems to be quite widely held that 0.002 ft.c. was solely a characteristic of the sprayed lamp.

Mr. Cunnington had also remarked that with white sprayed lamps used in existing fittings, he considered the visibility obtained was, in fact, better than that provided by the standard fittings for a spacing height ratio of 4 : 1. Mr. Maxted considered that this was primarily attributable to reduction in source brightness due to spraying, and pointed out that in the revised BS/ARP 16, the Committee had adopted fittings using a low source brightness.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—"Trans. Illum. Eng. Soc. (London)."

PROVISIONAL PROGRAMME OF MEETINGS (SESSION 1941-1942)

In what follows we give a provisional list of meetings of the Society in prospect in London and elsewhere. All available particulars of forthcoming events have been included, but it will be understood that in some instances programmes for the entire session have not yet been completed, and that local conditions may necessitate certain changes, for example, in the time of meeting.

In the meantime, members are advised to keep this list for reference purposes. Notices of individual meetings will be issued to members resident in the areas in which they are held. Any modifications in the programme announced and any further events arranged will be brought to their notice in due course.

It will be noted with interest that, in addition to the five existing Centres, a new group of members has been formed in the South Wales area, and that arrangements for the holding of meetings in Cardiff up to the end of the present year have already been completed.

GENERAL MEETINGS IN LONDON.

Unless otherwise announced Meetings will be held at **2.30 p.m.**

1941.

Tuesday, October 14th. Address by The President (Mr. W. J. Jones), on **"Light and Lighting—A Forward Outlook."** *To be held at the E.L.M.A. Lighting Service Bureau, 2 Savoy Hill, London, W.C.2.*

Tuesday, Nov. 11th. A Paper on **Industrial Lighting in Relation to Reconstruction** by Mr. H. C. Weston. *To be held at the E.L.M.A. Lighting Service Bureau, 2 Savoy Hill, London, W.C.2.*

Tuesday, Dec. 9th.

1942.
Tuesday, Jan. 13th.
Tuesday, Feb. 10th.
Tuesday, March 10th.
Tuesday, April 14.

Papers on **Infra Red Radiation for Drying Processes; Daylight Illumination; Advance Planning of Public Buildings; Outdoor Lighting; Dock Lighting, etc.**

Tuesday, May 12th. Annual General Meeting.

NORTH MIDLAND CENTRE.

(*Hon. Secretary:* W. F. Pogson, 4, Albion Street, Leeds, 1.)

Unless otherwise announced Meetings will be held at The Great Northern Station Hotel, Leeds, at **3.0 p.m.**

1941.

Oct. 15th. Luncheon for Members and their Guests. **12.30 p.m.** for **1.0 p.m. Annual General Meeting** at **2.30 p.m.,** followed by General Meeting at which the President (Mr. W. J. Jones) will deliver an Address.

Nov. 10th. Paper on **The Manufacture of Glass,** with particular reference to Lighting Fittings, by Dr. W. M. Hampton.

1942.

Mar. 9th. Paper on **Colorimetry,** by Mr. F. L. Warburton.

Apl. 13th. Paper on **Light Adaptation with special reference to Working Conditions,** by Mr. W. J. Wellwood Ferguson.

NORTH WESTERN CENTRE.

(*Hon. Secretary:* Alan H. Owen, 11, Albert Square, Manchester, 2.)

Unless otherwise announced all Meetings will be held in the Reynolds Hall of the Manchester College of Technology, Sackville St., Manchester, at **2.30 p.m.**

1941.

Oct. 16th. Address by the President (Mr. W. J. Jones).

Nov. 13th. Four short Papers by members.

Dec. 11th. Paper on **Factory Lighting,** by Mr. H. C. Weston.

1942.

Jan. 15th. Subject to be announced.

Feb. 12th. Subject to be announced.

Mar. 12th. Paper on **Colour Vision,** by Mr. W. J. Wellwood Ferguson.

MIDLAND CENTRE.

(*Hon. Secretary:* C. J. Allderidge, 10, Boscobel Road, Walsall.)

Unless otherwise announced Meetings will be held at The White Horse Hotel, Congreve Street, Birmingham, at **6 p.m.**

1941.

Sept. 26th. Address by the Chairman (Mr. P. J. Watson).

Oct. 24th. Address by the President (Mr. W. J. Jones).

1942.

April 17th. A Paper on **The Eye,** by an Ophthalmic Surgeon.

May 15th. Lighting Terminology. A Popular Discourse by Mr. C. F. Partridge.

June 12th. Paper on **Lighting in Architecture** by An Architect.

SCOTTISH CENTRE.

(*Hon. Secretary:* M. W. Hime, E.L.M.A. Lighting Service Bureau of Scotland, 29, St. Vincent Place, Glasgow, C.1.)

Unless otherwise announced Meetings will be held at The Gordon, Gordon Street, Glasgow, at **6 p.m.**

1941.

Oct. 29th. Address by the President (Mr. W. J. Jones).

Dec. 17th. Discussion on **Post-War Reconstruction.**

1942.

Feb. 18th. Subject to be announced.

NOTTINGHAM CENTRE.

(*Hon. Secretary:* C. S. Caunt, 62, Thackeray's Lane, Woodthorpe, Nottingham.)

Unless otherwise announced Meetings will be held in the Lecture Theatre of the City of Nottingham Gas Dept., Parliament Street, Nottingham, at **5.30 p.m.**

1941.

Sept. 26th. Paper on **Electric Discharge Lamps and their Application to Photographic Processes** by Mr. H. A. J. Turner.

Oct. 17th. Address by the President (Mr. W. J. Jones).

1942.

Feb. 27th. Paper on **Post-War Developments in Colour Lighting,** by Mr. R. Gillespie Williams.

Mar. 27th. Problem Meeting (contributions by various Members).

SOUTH WALES GROUP.

Hon. Secretary: S. G. Turner, Mervyn House, Frederick Street, Cardiff.

Unless otherwise announced Meetings will be held at **3.30 p.m.**

1941.

Oct. 2nd. Address on **The Fundamental Lighting Principles,** by Prof. R. T. Dunbar, including Visit to Laboratories. *To be held at the Lecture Theatre, Physics Dept., University College, Cathays Park, Cardiff.*

Nov. 6th. An Address, with demonstrations, on **The Physiological Aspects of Lighting,** by Dr. J. H. Saxby. *To be held in the Lecture Theatre of the Medical School, University College, Newport Road, Cardiff.*

Dec. 4th. An Address on **The History of Lighting in Mines—1740-1941),** by Prof. T. David Jones. *To be held in the Lecture Theatre of the Medical School, University College, Newport Road, Cardiff.*

SESSION 1941—1942

THE I.E.S. COUNCIL.

President :—W. J. Jones, M.Sc., M.I.E.E., F.I.E.S.

Vice Presidents :—R. O. Ackerley, F.I.E.S., H. Buckley, F.Inst,P., F.I.E.S., E. J. Stewart, M.A., B.Sc., F.I.E.S.

*Members of Council** :—T. Catten, Dean Chandler, R. W. Daniel, G. Dixon, W. J. Edwards, N. V. Everton, C. E. Greenslade, G. W. Golds, J. W. Howell, W. M. Hampton, H. Lingard, Howard Long, R. Maxted, C. W. M. Phillips, J. S. Preston, T. E. Ritchie, W. F. Pogson, K. F. Sawyer, E. B. Sawyer, E. Stroud, Crawford Sugg, J. M. Waldram, H. C. Weston, W. D. Wright.

Hon. Treas. :—E. W. Murray. *Hon. Sec.* :—J. S. Dow.

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*In addition all Past Presidents of the Society, and the Chairman of recognised Centres (during their term of office) are *ex officio* Members of Council.

I.E.S. CENTRES AND GROUPS.

North Midland Centre:

Chairman : W. Hetherington. *Vice-Chairman* : E. C. Walton. *Hon. Secretary* : W. F. Pogson. *Hon. Treasurer* : W. H. Harris. *Committee* : L. Bridgewood, J. G. Craven, F. Firth, J. W. Howell, T. C. Holdsworth, W. I. Ineson, A. Kelso, R. O. Seville, A. Southern, J. W. Whitaker. *Hon. Social Secretary* : H. Peters. *Hon. Development Secretary* : J. H. Mollan. *Hon. Auditors* : E. Dunn, G. Casperson.

North-Western Centre:

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Midland Centre:

Chairman : P. J. Watson. *Hon. Treasurer* : F. F. Middleton. *Hon. Secretary* : C. J. Allderidge. *Committee* : F. Roper, F. C. Johnson, H. S. Allpress, F. C. Dain, W. J. G. Davey, P. Hartill, J. G. Holmes, P. Hulse, A. J. Pashler. *Ex Officio* : F. S. Ette, W. M. Hampton and Howard Long.

Scottish Centre:

Chairman : E. J. Stewart. *Vice-Chairman* : J. H. Scott. *Hon. Secretary* and *Hon. Treasurer* : M. W. Hime. *Committee* : J. Dickson, T. Gavin, F. Hailstones, E. M. Hood, S. B. Langlands, D. MacFarlane Macleod.

Nottingham Centre:

Chairman : M. Wadeson. *Hon. Secretary* : C. S. Caunt. *Committee* : J. C. Charity, A. C. Collard, A. Hacking, G. C. Hadfield, A. G. Kidd, W. Jackson, G. D. Johnson, E. G. Phillips, T. E. S. Thwaite.

South Wales Group:

Chairman : Edward Jones. *Hon. Secretary and Treasurer* : S. G. Turner. *Committee* : Prof. T. David Jones, C. S. Chubb, T. E. Alger, R. J. Auckland, J. H. Dinham, D. C. James, A. E. Luen, C. J. Page, T. Scott Harrison, W. H. Stone, V. G. Wackrow.

NEW I.E.S. "GROUPS"

As a result of recent discussions agreement has been reached on methods and arrangements to facilitate the development of I.E.S. Centres in new areas by means of "Groups" which may consist initially of about twenty or more members. Such a group has recently been formed in the South Wales area and is now in operation. For some little time a movement towards the formation of a similar group in the Bristol-Bath area has also been in progress.

News has now been received of a meeting held in Newcastle on September 11, at which a decision to form a group in the North-Eastern area was taken. Mr. J. W. Howell, the chairman of the North Midland Centre, in whose area of operations the new group will operate, presided. Already a number of applications for membership from this area have been received.

LIGHTING AND RECONSTRUCTION

The part to be played by lighting engineers in reconstruction problems will figure prominently in the programme of papers for the coming session (see page 115). As desired at the annual general meeting of the Society last May, the Council is also studying this problem by the aid of a special committee, under which sub-committees and panels to deal with special aspects are being developed.

The Honorary Secretary would be pleased to hear from any members willing and able to serve on such committees and to aid the Society with their knowledge of special fields of lighting.

APPLICATIONS FOR MEMBERSHIP.

In accordance with the procedure outlined in the Revised By-laws the following applicants have been duly elected by the Council to Membership in the Society and their names have been added to the list of members:—

Corporate Members:—

Childs, J. S. E. .....44a, High Street, Cowbridge.
Frisby, J. K.....20, Strangeways, Watford, Herts.
Law, N. L. .....28, Warser Gate, Nottingham.
Springsgeith, C. E. ...14, Llanfair Road, Penygraig, Rhondda.

Associate:—

Hillier, R. .....225, Tulibardine Road, Ecclesall, Sheffield.

Student:—

Prothero, G. J. .....1, Leigh Road, Pontnewynydd, Pontypool, Mon.

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THE MEASUREMENT OR GAUGING OF LOW VALUES OF ILLUMINATION AND BRIGHTNESS

By J. W. T. WALSH, M.A., D.Sc. *(Fellow)*

(Paper read on April 8, 1941).

ABSTRACT.

Present-day problems in illuminating engineering call for the measurement of very low values of both illumination and brightness. Such measurements are difficult, both on account of the reduced sensitivity of the eye to brightness differences and because of the operation of the Purkinje effect. The need is generally for measurements which will represent what is experienced under practical conditions, and so coloured light is measured by visual comparison with white and the results are termed values of "apparent illumination" or "apparent brightness." The particular features required in illumination gauges and illuminometers suitable for measuring low values of illumination are described, with special reference to the appropriate British Standard Specifications. For certain purposes a portable standard of brightness is convenient, especially where the use of a gauge is awkward or impossible. In the study of luminescent materials a special type of brightness gauge is used, capable of measuring apparent brightness down to 0.0001 foot-lambert.

Introduction and Summary.

In many problems of lighting under present-day conditions it is necessary to measure values of illumination which are not so conveniently expressed in foot-candles as in milli-foot-candles, and a need has therefore arisen for instruments capable of measuring these very low values. In different sections of the Lighting (Restrictions) Order, 1940, mention is made of the following maximum values of illumination permissible for certain purposes:—

0.001 ft.c. at ground level outside a public vehicle (§25c).

0.002 ft.c. for railway stations, docks, etc. (§§45e, etc.).

0.1 ft.c. on the seats of a public service vehicle (§25b).

0.02 ft.c. and 0.2 ft.c. are also values which may be permitted.

In certain circumstances, if it is desired only to test for compliance with the Regulations, clearly all that is necessary is an illumination gauge, analogous to the "not-go" gauge of the mechanical engineer, which will give a clear indication whenever a specified value of illumination is exceeded. For experimental purposes, or for design, however, it is necessary to have something more than this, and an instrument by means of which the actual value of the illumination can be measured to a satisfactory degree of accuracy must be provided.

Not only values of illumination, but also certain limiting values of brightness are specified in the Lighting (Restrictions) Order, viz.:—

0.02 e.f.c. for shop signs (§40).

0.5 c./sq. ft. for refuge lamps (§6d).

and in B.S./A.R.P. 32 it is specified that the brightness of an illuminated A.R.P. sign shall be between 0.04 and 0.1 e.f.c. A gauge, or a measuring instrument for brightness, or both, is therefore needed, too.

Some of the more outstanding difficulties inherent in making measurements of this kind, and details of the design and use of instruments at present available for the purpose, are dealt with in the following paragraphs.

Difficulties.

The difficulties are twofold. There is first the fact that the precision of any visual photometric measurement depends on the minimum contrast which the eye can just detect and, as it is impossible by any optical means to increase the brightness of a surface, it follows that the lower the illumination to be measured the less will be the precision attainable even under the best conditions.

Then there is the difficulty due to a possible difference in colour between the illumination to be measured and the light provided by the comparison source within the instrument. In this connection it is well to remember that, owing to the fact that the eye is very insensitive to colour at low values of brightness, one can easily live in a fool's paradise. The well-known Purkinje effect that, as the brightness viewed diminishes, light of shorter wave-lengths (at the blue end of the spectrum) is weighted more and more in comparison with light at the other end of the spectrum, does not cease just because the

eye can no longer detect a colour-difference. As long as the lights compared differ in their spectral composition, so long must the Purkinje effect be taken into consideration.

Contrast Sensitivity.

The minimum difference of brightness which the eye can just detect is, fortunately, fairly well known for a wide range of values of brightness, at any rate for white light. It will be seen from Fig. 1 that,

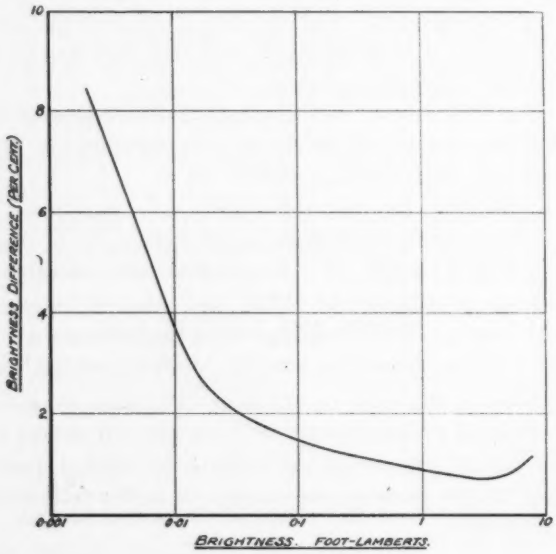

Fig. 1.

whilst a contrast of about 1 per cent. is detectable under ordinary conditions, when the brightness falls to 0.01 foot-lambert* this percentage rises to about 4, while at 0.001 foot-lambert it is probably as high as 10. Since no one, probably, would claim to be able to make settings on an illuminometer under normal conditions closer than about 2 per cent. it must be concluded that 20 per cent. represents about the best that can be expected of a skilled observer when the illumination on the test plate is 0.001 ft.c., and no doubt for an unskilled, or semi-skilled observer the performance would not be as good as this.

Colour Difference.

The onset of the Purkinje effect from a brightness of about half a foot-lambert downwards makes it necessary to re-define, or to define more precisely, the meaning of values of illumination or brightness measured with an ordinary illuminometer or brightness gauge when these values are very low. It might, for instance, be agreed that all values should be expressed as fractions (obtained by some mechanical means such as a sector disc or a neutral filter) of some brightness well above the limit mentioned above. In this case a surface illuminated by a source of blue light of intensity 0.4 candle would be said to have an illumination of 0.001 ft.c. if placed at a distance of 20 ft. from the source, and the same would be true if the source provided white light or red light or light of any colour whatsoever. Unfortunately a normal observer, if he were to compare these different illuminations visually, would adjudge them to be far from equal. He would say unhesitatingly that the illumination by the blue light was higher than that under the white light, and that both were much higher than when the light was red. In other words, the system of measurement would fail to give results even roughly in agreement with visual impression.

The alternative is to base the scale of measurement on mechanical sub-division of a high illumination by light of *one* agreed colour and to assess values for all other colours by visual comparison with this. Clearly the results so obtained will agree with the judgment of "the man in the street," and a system of this kind has now been adopted for such practical matters as the measurement of the brightness of fluorescent and phosphorescent paints. The agreed colour in which the scale is set up is that of the light given by a tungsten filament vacuum lamp (colour temperature 2360°K). In most illuminometers the comparison lamp inside the instrument gives light of this colour quite closely enough for all practical purposes. It follows then, that the illumination of a surface by coloured light should be measured by means of an illuminometer used in the ordinary way, no attempt being made to "correct" the colour of the test light by interposing a compensating colour-filter between it and the instrument.

It must, of course, be realised that on this system one cannot apply the inverse square law to the calculation of illumination in the case of coloured light. For instance, if a certain blue lamp gives an illumination of 1 ft.c. at a distance of 5 ft., the illumination at a distance of 50 ft. will *not* be 0.01 ft.c., but something considerably greater. For a red lamp of the same candle-power, on the other hand, the illumination at 50 ft. will be considerably less than 0.01 ft.c. To avoid the confusion that might arise from this

*The foot-lambert is the unit sometimes referred to as the equivalent foot-candle, i.e., the brightness of a perfectly diffusing surface of 100 per cent. reflection factor when the illumination of the surface is 1 ft.c.

sort of result, illumination measured in this way may be termed "apparent illumination" if the light is coloured, just as brightness so measured is termed "apparent brightness." From what has just been stated it follows that if two surfaces have equal apparent illuminations by light of different colours, then if both illuminations are increased or decreased in the same ratio by mechanical means, the resulting apparent illuminations are no longer equal in the region over which the Purkinje effect is operative.

There is one further matter that must be mentioned in connection with the measurement of apparent illumination or apparent brightness. This is the fact that the Purkinje effect is absent, or, at any rate, unnoticeable, when the angular size of the surface viewed is small. For this reason it is recommended that when measurements of illumination or of brightness are being made, the size of the field of view should be at least 5 degrees under normal conditions of use. The form of field inwhich the two parts are side by side is generally preferable to the concentric type; if the latter is used the diameter of the central area should be at least 3 degrees.

Illumination Gauges.

Several types of instruments have been devised to enable low values of apparent illumination to be gauged. One form depends on the use of a self-luminous radio-active compound to illuminate the comparison surface. This instrument has already been demonstrated to the Society*, and a description of it as commercially available has recently appeared.† It does not seem necessary, therefore, to give a detailed description of it here. The other commercial form of gauge is, in essence, an illumination photometer with provision for fixing the controlling handle at one or more positions corresponding to the values of illumination to be gauged. This instrument, too, has been demonstrated to the Society and described in "Light and Lighting."‡

Both of these instruments have been designed to comply with the Specification B.S./A.R.P. 30 of September, 1940, in which the various matters mentioned earlier in this paper have been taken into consideration.§ For instance, a lower limit is placed on the brightness of the field of view. This is clearly desirable on account of the rapid reduction of contrast sensitivity with brightness (see Fig. 1). Linked with this is the requirement in the specification that if there is an eyepiece in the instrument the aperture shall have a diameter of at least 7 mm. This is important, because the brightness of the image on the retina is reduced by any stop which is smaller than the natural pupil and it is, of course, this brightness that controls the contrast sensitivity. It is therefore useless to demand a certain brightness for the field of view and then to allow this to be reduced by the introduction of a stop in the eyepiece. An appendix to the specification give some useful hints on the use of gauges for checking low values of illumination, and draws particular attention to the need for thorough dark-adaptation of the observer.

Illuminometers for Low Illumination.

Instruments intended for measuring very low values of illumination do not generally differ in their essentials from other types of illuminometer to which the illuminating engineer is accustomed; in fact, the need for a specification for such instruments has been met by quite brief additions to the ordinary Specification for Portable Photometers (Visual Type) (230—1935). The new range introduced is 0.0005 to 0.3 ft.c., and the corresponding limit of error laid down is 20 per cent., plus 0.0001 ft.c. Otherwise there is but little change, but, of course, the various considerations mentioned earlier in this paper must be borne in mind.

There is one important difference between an illumination gauge and an illuminometer (quite apart from the fact that the former is for use at definite values only), and it is a difference that is not always clearly understood. With an illuminometer the observer can change the illumination of the comparison surface fairly rapidly, and the usual practice is to go out of balance, first on one side and then on the other, two or three times in succession, finally making a setting which is roughly mid-way between the two just-out-of-balance positions. The result should be a setting which is considerably closer to the true value than the percentage contrast which the eye can detect. To illustrate this point it may be recalled that the best the eye can do in the detection of contrast is about 1 per cent., yet visual photometry to an accuracy of a quarter, or even one-tenth, of this is by no means impossible on the photometer bench.

With a gauge, on the other hand, it is only possible to judge when the illumination is greater or less than the value to which the gauge is set, by an amount

* "Light and Lighting," November, 1939, p. 231.
† Ibid., December, 1939, p. 232, and January, 1941, p. 3.
‡ December, 1939, p. 231.
§ "Light and Lighting," February, 1940, p. 22, and November, 1940, p. 186.

equal to the minimum contrast just detectable under the existing brightness conditions. Thus, for example, if the gauge is set to 0.02 ft.c., and the brightness of the field of view is the minimum permissible in BS/ARP.30 (say, 0.0002 foot-lambert), so that the contrast sensitivity of the eye is probably about 25 per cent., the field of view will go out of balance at 0.02 ± 0.005 ft.c. if the setting of the gauge itself is perfectly accurate. In other words, the value checked by the instrument when used as a "not-go" gauge is 0.025 ft.c. and not 0.02 ft.c. Actually, since the experiments on which Fig. 1 is based were carried out under laboratory conditions, it is probable that under the conditions of use common in the case of illumination gauges the contrast sensitivity of the observer's eye is considerably lower and the figure is more likely to be about 0.03 ft.c. in the example given above.

Brightness Gauges.

As mentioned at the beginning of this paper, there is a need for an instrument capable of checking various low values of brightness, and it is clear that, as in the case of ordinary values of brightness, instruments suitable for measuring illumination can, in most cases, be used for measurement of brightness. Both the types of illumination gauge referred to earlier in this paper can, in fact, be used to gauge brightness, but in some cases this is inconvenient on account of the inaccessibility or small angular dimensions of the surface to be gauged, its marked coloration, or some other reason. In consequence, a specification has recently been issued (BS/ARP 52, Dec., 1940) for a portable piece of apparatus which provides a standard of comparison by which to judge the brightness of any sign, refuge lamp, etc.* The values to which the standard can be set are to be 0.02, 0.04, 0.1, and 0.5 foot-lambert, and in an appendix to the specification a description is given of a piece of apparatus capable of fulfilling the requirements. It consists, in essence, of a box containing a lamp fed from a portable battery, one side of the box having a white translucent window, the brightness of which is adjusted to the required value by means of a resistance in series with the lamp. Red or blue screens can be placed over the window when the surface to be gauged is coloured. It is emphasised that the values to be gauged are values of *apparent* brightness.

A special problem in brightness measurement which has recently come into prominence is that met with in studying the performance of luminescent materials. In the specification for these materials (BS/ARP.18)* it is laid down that the brightness under stimulation shall be not less than 0.1 or 0.01 foot-lambert (depending on the class of material), and after a stated time in the dark the brightness shall be at least 0.0001 foot-lambert. In all cases it is apparent brightness that is specified, and the importance of this will be clear when it is remembered that the light given by a luminescent material may be of almost any colour whatsoever. A form of brightness gauge suitable for this particular class of work has been devised and is described in the specification. It is an "open-view" type of instrument; there is no eyepiece, and both eyes are used when making the observations. No colour filters are used, and the observer has to make his judgment* in the only way possible when measuring apparent brightness, viz., without regard to colour. At the lower values, of course, the disturbing effect of colour difference becomes much less as the eye becomes more and more insensitive to colour.

Conclusion.

From what has been described above it will be seen that present-day conditions have presented the photometric laboratory with new problems. Strictly, of course, the problems are not new, but their existence, although realised, has been largely ignored because they have not hitherto entered into ordinary photometric practice. The necessity for measuring apparent brightness, rather than brightness based on a physical scale, is perhaps the most striking of these new developments. To those who began to think that no further progress could be looked for, at any rate in visual photometry, the present situation comes as a challenge and a welcome stimulus.

* "Light and Lighting," Jan., 1941, p. 10.

* "Light and Lighting," Nov., 1940, p. 185.

VISIBILITY BY WHITE AND COLOURED LIGHT

By J. S. DOW, B.Sc., A.C.G.I. *(Fellow)*

(Paper read on Tuesday, April 8, 1941)

The title adopted for this paper relates primarily to the degree of ease with which the objects illuminated by white or coloured light can be seen or recognised at a distance—not to the perception of distant luminous signals, which constitutes a somewhat different problem. It is also proposed to consider mainly the effect at considerable distances of the order of miles, and at moderate distances, such as are involved in making one's way about or in recognising objects across the street. The effect at very short distances, i.e., at reading distance or less, which involves somewhat different factors, will only be considered incidentally.

Choice of Colour for Outdoor Lighting in General

The problem has come into some prominence in connection with the study of A.R.P. problems. The comparative visibility of areas illuminated respectively by blue and white light, when viewed from above at a height of one or more miles, was one of the first problems to be considered by the expert I.E.S. Committees. As a matter of general policy it was necessary to decide whether there was any substantial advantage in adopting light of any particular colour. At that time various hastily improvised systems of emergency outdoor lighting, in which lamps and globes painted in blue lacquer figured largely, were being contrived. The use of blue lacquer was doubtless due mainly to the fact that this is one of the readiest means of obscuring light, though there was also prevalent an impression that the choice of blue light in itself diminishes visibility at a distance.

In so far as this problem of general outdoor lighting is concerned, a decision was readily reached. The use of coloured light is on the whole inexpedient, because unusual colour in itself tends to attract attention and because it can only be attained on a large scale by subtractive processes, which are essentially uneconomical. To obtain anything approaching pure blue light from an incandescent electric lamp, for example, it is necessary to adopt filters, which reduce the light to less than 1 per cent. of its original value. Even if one is satisfied with an apparently "blue" but really mixed light, the loss is very considerable. Furthermore, blue lacquers and paint are liable to deteriorate and flake off and it is difficult to secure permanency. Unless, therefore, any very substantial advantage in using blue light could be proved, it seemed better to base methods of general lighting on the use of white light.

There can be no harm in recording, what has always been publicly stated, that experiments did not reveal any such material advantage such as would offset the drawbacks mentioned above. For reasons that will appear, there is likewise no reason to advocate the general use of light from other parts of the spectrum, such as red and orange. Accordingly systems of general lighting, such as the special war-time street lighting, have been based upon the most economical use of white light. It is reported that a similar conclusion has been reached in Germany.

Special Problems

This decision in regard to general lighting does not, however, exclude the possibility that there might be some advantage in using light of some special colour under special conditions. For example, over a relatively small area, in which light from electric discharge lamps equipped with suitable filters could be specially installed, the waste of light involved would be very much less and a reasonable degree of permanency could be secured. For certain processes and operations there might prove to be advantages in some form of coloured light—especially if the influence of this colour on visibility at a distance were also taken into consideration. In view of the changing behaviour of the eye towards coloured light with diminishing illumination (the Purkinje effect), a decision might prove to depend to some extent on the order of illumination to be maintained.

Viewed in this broad aspect, this is not primarily a war-time problem. It has, for example, a bearing on street lighting installations. The fact that in time

to come our facility in producing economically light of any desired colour will doubtless be still further improved, renders the problem one of general interest.

In what follows it is proposed to present a brief analysis of the relevant factors, which have often been the subject of reference in papers on technical subjects. Some of them, indeed, have been treated very fully in textbooks on physiological optics issued many years ago, though their bearing on modern lighting problems is not always fully appreciated.

The main factors in the problem appear to be: (1) The Purkinje effect; (2) Selective absorption by the atmosphere; (3) the influence of colour on acuteness of vision; and (4) the influence (if any) of colour on visual ability in other respects, such as speed of perception. To these might be added (5) special circumstances arising from the purpose served by the light provided, which might favour the choice of some particular colour. This factor, however, cannot be precisely defined and scarcely comes within the scope of the problem now being considered.

The Purkinje Effect

To members of the Illuminating Engineering Society who are familiar with the lucid exposition recently contributed by Dr. J. W. T. Walsh*, it should hardly be necessary to describe this effect in detail. It may, however, be recalled that "the Purkinje effect" relates to the peculiar behaviour of the eye towards colours in weak light. At low illuminations the eye is relatively much more sensitive to the blue end of the spectrum than to the red. Hence, at low illuminations the apparent brightness derived from a source of green or blue light may be very much greater than that derived from a similar source of red light, though the calculated illumination may be the same. At a very low order of illumination the sense of colour is lost. The red sensation then fades out completely (so that red-coloured objects appear black), whilst the blue sensation still persists (blue objects appearing a faint grey).

This change in sensitiveness is complicated by the fact that the centre of the eye, whilst it still retains sensation, is more sensitive to the red end of the spectrum than to the blue end, whilst for the peripheral region of the retina the reverse is the case. Hence, if two patches of red and blue light appear equally bright at close quarters, we may find, as we walk backwards, that the red becomes the brighter of the two—because the patches are now received on the small central region of the retina. As the illumination is diminished, however, we ultimately reach a point where this central region of the retina becomes relatively insensitive, vision being effected mainly by the peripheral region, which still retains its high sensitiveness to blue light.

* "The Reds and the Greens," "Light and Lighting," Oct., 1940, p. 162.

Selective Absorption by the Atmosphere

This is a subject on which much has been written and many conflicting opinions expressed. It seems to be generally agreed, however, that, whilst the degree of selection depends greatly on atmospheric conditions, the tendency is for the light of the shorter wavelengths to be most readily absorbed and scattered by minute particles. In confirmation, such familiar facts as the red and orange colour of the transmitted light at sunset and the blue luminous haze (due to scattered blue light) which colours distant mountains have often been quoted. The accentuation of the blue end of the spectrum of sunlight, and especially the ultra-violet, on the summits of high mountains is again evidence in the same direction. Such effects, however, take place through a considerable depth of atmosphere. The importance of the effect at relatively short distances is perhaps open to question. Nevertheless, this is a factor that must be taken into consideration in assessing the visibility of coloured light when viewed from a distance of some miles. The fact that absorption is effected mainly by scattering should not be overlooked. Such scattering may give rise to a certain glow which might itself become visible at a distance.

Influence of Colour on Acuteness of Vision

This, too, must be regarded as a controversial question. Just as the selective action of the atmosphere has been quoted in advocacy of yellow beams for motor car headlights, so there is a tendency to accentuate the influence of colour of light on acuteness of vision. The author discussed this point somewhat fully in a paper read before the Society about twelve years ago.* Attention was then drawn to the important bearing on this question of the want of achromatism of the human eye, in virtue of which images of objects illuminated by red and blue light are displaced either side of the focusing position for white light. The influence of this factor varies with different eyes and the nature of their optical effects. A few people with good powers of accommodation can apparently focus on either the red or the blue with almost equal facility. But, in the author's experience,

* "The Illuminating Engineer," June, 1928, p. 167.

the majority find that in the case of distant vision (more than 10 ft. or so) it is difficult to focus on blue light, and correspondingly easy to get a sharp image of the red, whilst for close vision (reading distances or less) the reverse is the case. This effect naturally influences experience with mixed light, the blue and violent constituents in which tend to create an impression of luminous haze, somewhat similar to that produced by the scattering effect of the atmosphere.

Item (4) is included chiefly in order to put on record the work of Mr. C. Dunbar on the influence of colour of light on speed of perception. His conclusion, based on researches summarised in a paper recently read before the Society is that colour of light appears to have little or no effect on the speed with which objects can be recognised.*

The special circumstances covered by Item (5) hardly fall within the scope of this article. As an instance, one might mention processes involving separation of material or the detection of stains and defects, and where light of certain spectral composition is therefore found to have advantages.

Application to Visibility Problems

The factors enumerated above have an evident bearing on the question of the visibility of illuminated areas, viewed from a distance. Except for the question of atmospheric absorption, which is difficult to explore in the laboratory, the conditions can be fairly well reproduced by the observation of white cards of equal and suitable size, illuminated by white and coloured light and viewed from the back of a fairly long room.

Assuming that the illumination is so adjusted that the cards appear to be of approximately equal brightness when observed at close quarters, one finds, as the distance of the eye is increased, that the card illuminated by red light becomes progressively brighter in comparison with that illuminated by pure blue or green light. If the illumination of all the cards is uniformly diminished this tendency becomes accentuated. But presently the eye becomes so much less sensitive to the red end of the spectrum that it becomes difficult to see the red-illuminated card, and ultimately it fades out completely.

Simultaneously there are two other effects to be noticed. One finds that at weak illuminations it soon becomes difficult to see any of the cards by direct vision (i.e., " looking straight at them ") because the centre of the eye has become relatively insensitive to light. A faint spot of blue light is easily visible by oblique vision (" out of the tail of the eye ") whereas it fades out completely if one looks straight at it and keeps the head still. With pure red light, however, there is no apparent accentuation in brightness when the object is viewed out of the tail of the eye. So long as the spot can be seen at all it is best seen by looking straight at it.

These effects are in accordance with familiar experiences of the Purkinje effect and the characteristic behaviour of the centre of the eye and the periphery in weak light. But the completeness with which they can be reproduced depends on the order of brightness at which the experiment is made.

Another fact, resulting from the want of achromatism of the eye lens, is that the red spot of light, so long as it can still be seen, not only tends to appear brighter but also sharper in outline than the blue, as the distance of the eye is increased. The latter, in fact, may become so fuzzy that the outlines cannot be clearly distinguished, especially if pure blue colour used.

If, therefore, one is anxious to render the shape and outline of some object indistinguishable at a distance, there seems to be some ground for advocating the use of pure blue light—more particularly as intervening atmospheric mist tends to scatter and absorb blue light to an exceptional degree.

This, however, applies primarily to direct vision. At low orders of illumination one becomes aware of illuminated areas chiefly by indirect vision, and one then finds that areas illuminated by blue light are particularly easily detected by the peripheral region of the retina. Thus the use of pure blue light in preference to white of similar brightness, whilst possibly making it more difficult for the dark-adapted eye to examine an illuminated object closely, renders it easier for the eye to become aware of its existence.

We have, therefore, to balance advantages and disadvantages. In practice it is not very easy to keep the head so still that a distant spot is received continuously, on the central region of the retina. One's judgment is therefore apt to be guided mostly by the experience of the peripheral region. On this basis tests tend to show no substantial advantage in using blue light in preference to white.

A consideration that is apt to influence discussion on this problem is the apparent great gain in visibility at close quarters resulting from the use of

* Visual Efficiency in Colour Light, Trans. Illum. Eng. Society, London, Vol. IV., No. 10, Oct., 1939, p. 137.

pure blue light—a natural result of the Purkinje effect. It must be considered, however, that visibility at a distance (which depends on actual brightness, not the calculated illumination) is likewise increased, though possibly not to the same extent. Furthermore, the utility of the illumination secured is possibly impaired by the fuzziness of outlines of objects when seen at some little distance. (This has been adduced as one argument against the adoption of blue light for destination-boards of buses; letters thus illuminated are difficult to determine when viewed at some little distance.)

Whilst, therefore, there is undoubtedly room for further study of the effects of coloured light at very low illuminations, it seems likely that the broad view that there is no substantial advantage in departing from the use of white light will in general be found to hold good.

Street Lighting

The facts discussed above are of interest in connection with modern street lighting. Immediately before the war, systems utilising the spectra sodium and mercury vapour had come into general use, and there has been some discussion on the alleged drawbacks and advantages of these two systems from a visual standpoint.

In street lighting we have frequently to deal with large and weakly illuminated areas the image of which occupies a relatively large space on the retina. In such circumstances the Purkinje effect has full play, and one is apt to receive an impression of great and even brightness from areas illuminated by mercury lamps—largely, the author believes, because of the spreading effect of light from blue line in the mercury spectrum. The impression of brightness might be somewhat less, but the sharpness of the objects illuminated greater if this line were suppressed by a filter.

With sodium light there may be, relatively, less apparent gain in brightness at very low illuminations, as sensitiveness to the central region of the spectrum fades out more quickly than in the remote green and blue. But, as a compensation, there may be a gain in sharpness and contrast owing to the fact that the yellow monochromatic light is brought into sharper focus by the eye. This is, however, admittedly debatable ground, as so much depends on the personal equation.

There is another factor besides chromatic aberration which may affect the apparent contrast at weak illuminations and with coloured light. It has sometimes been claimed that an apparent contrast, due to difference in the reflecting power of adjacent objects, becomes relatively greater with sodium light than with mercury light at a low order of illumination—because of the different rate of growth of the sensations in the yellow and in the green and blue. When one considers that the red sensation fades out at a point when the green-blue sensation is still active, one can imagine an effect such as that mentioned above—though it would apparently only come into play at a certain very low order of illumination.

Very Close Vision

Throughout this address the author has been concerned mainly with relatively distant vision. No attempt has been made to consider tasks involving very close vision, in which connection somewhat different conclusions in regard to the utility of coloured light might well be reached. It is true that, even in this field, recent researches tend to suggest that there is no pronounced advantage in using light of any specific colour. Nevertheless, there does seem some ground for believing that there may be opportunities here for the use of pure blue and violet light —more especially in connection with processes where the eye is necessarily brought very close to the object for long periods and where glasses for the purpose of magnification or in order to diminish the effect of accommodation have been found beneficial.

It has also sometimes been claimed that, in processes involving the inspection of very minute objects there is an inherent advantage in using blue and violet light somewhat similar to that experienced in using the microscope, where the limit of resolution is a factor of the wavelength of light. On this point the author cannot speak with experience and would welcome expert information.

[In the course of this address the author arranged demonstrations of some of the effects mentioned. The audience were invited to study the appearance, at close quarters and at a distance, of the filament of a bare bulb tungsten lamp, screened by cobalt glass (with transmission bands in the red and blue), and especially to observe the tendency for a red centre, surrounded by a blue halo to be formed at a distance. Faint images of red, violet, and white light, projected on a screen, were studied in a similar manner. Finally, attention was directed to the appearance of black letters on a white ground, circles and models of figures of people when illuminated by faint light of various colours, attention being drawn specially to apparent differences in sharpness of outline.]

DISCUSSION

Lieut.-Col. K. EDGCUMBE, referring to Dr. Walsh's paper, said he was very glad the author brought out so clearly the difference between a gauge and a photometer. This bore out what he had always felt, viz., that the photometer, owing to the ease with which it could be put out of balance in each direction, gave very much greater accuracy than the corresponding gauge. At the same time, he would hardly like to go as far as ten times the accuracy, which was the figure given by Dr. Walsh. He would have put it at some five times.

Commenting on the footnote in Dr. Walsh's paper, stating that the foot-lambert was "sometimes referred to as the equivalent foot-candle," he said he hoped that Dr. Walsh would in future use the term "equivalent foot-candle." He noticed that in Fig. 1 brightness was expressed in foot-lamberts, but that might be a war-time economy, as Dr. Walsh might already have had the block of Fig. 1 and thought he would use it! Everyone knew what a foot-candle was, so that the "equivalent foot-candle" gave an idea of the level of illumination and he personally much preferred it to the foot-lambert. How many members of the Society knew what a lambert was?

A third, and more important, point was that Dr. Walsh stated: "For instance, if a certain blue lamp gives an illumination of 1 ft.c. at a distance of 5 ft., the illumination at a distance of 50 ft. will *not* be 0.01 ft.c., but something considerably greater." Was that true? He had always assumed that illumination (as distinct from brightness) was a physical question and not a physiological one. The brightness was obviously "apparent brightness," but when one spoke of "apparent illumination," as Dr. Walsh did, it seemed to him that one was knocking all solid ground from under one's feet. Just as the physicists of the last century used to ascribe to the ether any property that suited them at the moment, so does Dr. Walsh ascribe odd properties to illumination, merely because he wanted to correlate illumination and brightness by a coefficient of reflection. Some physiological coefficient must be put into the formula, no doubt, but he did not like the idea of "apparent illumination." Illumination was their sheet anchor.

THE PRESIDENT said that when he looked at the blue lamp from the back of the lecture room he saw an apparent horizontal bar which was a kind of blue and above that was a bright red misty patch, with a slight tendency to a similar thing below. When he lifted his glasses the immediate result was that he saw the red at the top and bottom with a general haze in the centre. The most prominent were the sharp bright lines at each end. He suffered from a very slight astigmatism, which was the only fault with his eyes. The other experiment upon which he did not agree with Mr. Dow was the three surfaces illuminated with red, green, and violet. To him the green gave the sharpest appearance when looking at the surfaces from the back of the room. He mentioned this because it was not the impression that Mr. Dow obtained and he would like to hear what other people had to say about it.

Mr. J. M. WALDRAM suggested that the cause of the coloured haloes seen when looking at a point source with a cobalt filter was that the focus for blue light was in front of the focus for red light. The colour of the image and the halo would depend upon where the individual happened to focus.

He disagreed with Dr. Walsh's use of the conception "apparent illumination." He had regretted even the introduction of the term "apparent brightness" as being liable to lead to confusion, but he felt very strongly that "apparent illumination," as a measure of the amount of coloured light falling on a surface, was completely meaningless. Brightness could, if desired, be properly expressed in "apparent" units; but it was impossible so to express illumination, because the answer would depend entirely upon the surface on which the light fell. To introduce apparent units into anything but the final brightness which resulted in a lighting installation would lead us very severely astray.

With regard to the use of blue, particularly in wartime, when it was necessary to restrict by regulations the amount of light used out of doors and elsewhere, he said there was a great difficulty in obtaining blue lamps the light output of which was controlled within reasonable limits.

With regard to atmospheric effect, he believed that unless very saturated colours were being used, the effect of selective absorption was very small. There was, however, another effect in the atmosphere which was important—the scatter, which was being studied more and more. He had been surprised to find in the course of experiments in his own laboratory that scattered light could amount to 5 per cent. in a length of only 90 ft. Since the amount of scattered light increased rapidly with distance, and since its effect was to desaturate colours, the chance of colour effects being important at a distance was small. Dr. Hopkinson and himself had made some experiments on the effect of sodium light mentioned by Mr. Dow, and he believed there might be a physical explanation. On the whole, however, the experiments showed that the effect was very small.

Mr. Waldram then showed a photometer which he had evolved for measurements down to very low levels of illumination, on a suggestion from an American source. Another principle which it employed had been suggested by Mr. Trotter many years ago. It was possible to make measurements down to about 0.000005 e.f.c. with the instrument.

Mr. J. S. PRESTON said that whilst Dr. Walsh had discussed one or two different forms of photometer for low illuminations, there was one photoelectric method which seemed to have been forgotten, viz., the old method of using the rate of charge of a condenser connected to the photocell to measure the photocurrent from the latter. Having drawn the circuit on the blackboard, Mr. Preston said this was a very simple and satisfactory system, using an electro-

meter triode as voltmeter across the condenser; and that for illuminations down to, say, 10^{-4} or 10^{-5} ft.c. the necessary apparatus was compact and fairly rugged.

Dealing with the question of coloured light, and a statement by Mr. C. E. Greenslade at a previous meeting that most normal sighted individuals can see more distinctly, under black-out conditions, with spectacles of −1 or 2 dioptres, he said one might advance the hypothesis that at these low levels the eye employed mainly blue light for vision, owing to the Purkinje effect. Since, owing to chromatic aberration, the normal eye is quite short-sighted for blue light, the recorded improvement in night vision resulting from the use of negative eye-lenses would then be explained.

Whether the hypothesis were justifiable, as an explanation of all or part of the observed effect, was dependent on the extent, under the prevailing conditions, of the shift of the effective wavelength towards the blue—a point requiring examination.

Dr. W. D. WRIGHT said there was a system of testing eyes which used the difference in focus between red and blue and he believed it was called the Duochrome system. The varied reactions to Mr. Dow's experiments were almost certainly due to the different refractive errors among the eyes of the audience.

Was the statement by Dr. Walsh that the Purkinje effect continued to exist even when the eye could no longer distinguish colour difference supported by experiment? It seemed very probable, so far as the blues and greens were concerned, but it would be interesting to know of any observations in this connection.

It had also been stated by Dr. Walsh that the Purkinje effect was absent, or at any rate unnoticeable, with a small field. Was that really true? If it were true, how small had the field to be before the effect disappeared?

In experiments which he was carrying out he used a two-degree field, but he found it very difficult to know just what part of the retina was actually being used when making colour matches at very low intensities. Had Dr. Walsh experienced the same difficulty?

The question had been raised by Mr. Dow as to whether it was an advantage in doing close work, as with a microscope, to use blue light. In his view, the eye was such an imperfect optical system that he was inclined to doubt it. Mr. Dow also mentioned the contrast when using mercury and sodium lamps at the lower levels of illumination. Having carried out some experiments—although, in view of Mr. Waldram's remarks, they might not be too good as he did not test the neutrality of the paper—he thought there could be no doubt at all that there must be some increase in contrast at the lower levels of illumination with the sodium lamps compared to mercury lamps.

Dr. H. BUCKLEY mentioned that in connection with Dr. Wright's remarks on the existence of the Purkinje effect in the presence of a colour match, there certainly was one if it was accompanied by an energy difference as in the photometry of sodium lamps. Here the usual colour match filter transmits practically all the visible spectrum except the blue and blue green. As to whether there was a Purkinje effect when the brightness was so low that colour was not appreciated there appeared to be no evidence.

He agreed with Dr. Wright that with small fields at low brightness it was difficult to fix vision in a definite and constant direction and to be sure that results obtained with, say, a 2° field did, in fact, apply to a 2° field surrounding the fovea. In practical photometry, using the ordinary photometers, Purkinje effects were, in fact, observed with 2° and even 1° fields. Similarly with regard to field size effects. There did not appear to be any portion of the retina, however small, which one could regard as being uniform in properties all over.

He inquired from Dr. Walsh why a 5° field had been specified for the measurement of luminiscent materials. The field size effect appears to be a continuous function of field size from 10° and 1°, over which range his own experience was limited. The use of a 10° field would make the photometry easier and perhaps more representative of the vision by which these materials were viewed in practice, viz., as Mr. Dow calls it, "out of the tail of the eye."

He agreed with Dr. Walsh that there were many points in visual photometry at low brightnesses in which we were short of information. Some of these were thought to be of academic interest, but recent developments had shown that they had practical importance as some case. In view of the fact that the visibility curves of real observers varied continuously with field brightness in the low brightness region, it seemed as if here, at any rate, was a region of photometry in which the usual method as opposed to physical methods involving photoelectric cells was the only one possible.

Mr. M. G. BENNETT said he had the impression that the further one got towards the red end of the spectrum the less did the light upset one's dark adaptation and the better one could see. Was that the general impression or not, because if it were true then there were many applications for red. He did not suggest using red matches to light cigarettes, but red lamps might be used for illuminating motor-car dash-boards, etc., which needed to be seen in the dark without upsetting dark adaptation. He believed that quite a lot of work had been done on the use of different colours, and perhaps Mr. Dow could make a statement on that point.

Mr. C. E. GREENSLADE, commenting on Mr. Dow's experiments, said he was able to see a distinct red centre with a blue haze. He was a little short-sighted, but when looking through a pinhole it was quite possible to see, according to the position of the pinhole, the red spot, but the blue spot turned round the red as the pinhole was moved in front of the eye. In a certain position of the pinhole the red and the blue corresponded. Speaking of negative glasses, he said that at 20 minutes to five that morning he had been making experiments in his garden and it was remark-

able, using negative glasses, to see how a white pebble stood out against the cultivated soil. At the same time he could not distinguish the difference in colour between the green grass and the rather dull sky or the black fence, yet the white stones stood out remarkably. That effect, however, did not occur without the spectacles. He attributed this not so much to the question of colour of the light as to the greater contrast with the smaller image.

Mr. R. MAXTED, referring to Mr. Dow's experiments, agreed with Mr. Waldram that the unnatural ability of some members to focus on the distant blue light, and not on the red, was usually due to the wearing of glasses. This result probably indicated an over-correction in the glasses. His own reaction was normal with one eye, but the other indulged in a vertical blue band and a horizontal red band.

Referring to both Mr. Dow's and Dr. Walsh's papers, Mr. Maxted said that when one was especially concerned with the visibility and the photometry of energy in the ultra-violet region, many of the effects and difficulties mentioned by the authors were found in an accentuated form. Even Dr. Buckley's subtle suggestion of a "Standard Curve for the A.R.P. Eye" must be regretfully rejected when the visual sensation ceased at about 3,000$\mu\mu$. In this region it was necessary to overcome the problems and prejudices connected with the use of the photo-voltaic cell or its equivalent.

At wavelengths below 3,000$\mu\mu$ there is very considerable reflection and dispersion by a few feet of apparently clear atmosphere, and one had the interesting conception of photometry performed in vacuo.

Even at wavelengths which were quite readily visible, the reduction in visibility due to haze could be appreciable at moderate distances.

Mr. A. CUNNINGTON recalled that on some of the new Southern Railway stations fluorescent tubes had been installed, of which a feature was the running of two parallel tubes, one of a reddish colour and the other of a blue-green colour, so that the combined effect gave a fair approximation to white light. These installations afforded an excellent opportunity of observing some of the effects mentioned in Mr. Dow's paper, and he particularly remembered an occasion when out for a walk and approaching one of these stations from over fields in an autumn evening he had noticed that at about half a mile distant the green colour was completely invisible. Gradually as one came nearer both colours became distinguishable, but it was not until one was close to the station that the two coloured tubes appeared normal.

Commenting on what Col. Edgcumbe had said with regard to the photometer and the gauge, he fully realised the advantages of using a photometer, but it was unfortunately necessary at times to call upon inexperienced people to make rough measurements, and he would in this case much rather hand them a gauge which was self-explanatory and with which it was hard to make a mistake. In his view there was a very definite field for the rough gauge as opposed to a photometer giving greater precision.

Dr. J. W. T. WALSH, commenting on a few matters mentioned in the discussion and promising a considered reply for the TRANSACTIONS, said the point made by Colonel Edgcumbe with regard to the gauge had been very adequately dealt with by Mr. Cunnington. As regards the foot-lambert, also mentioned by Colonel Edgcumbe, he felt that that was largely a matter of taste. Personally, he hated the term "equivalent-ft.-candle" and would not use it unless he was obliged. It was used in the A.R.P. specification and in the Lighting Restrictions Order, but it seemed to him an illogical name and one to be avoided.

Both Colonel Edgcumbe and Mr. Waldram had criticised him severely for speaking of "apparent illumination," and there was a lot in what they said. At the same time, he felt there was no escape from it. He realised it was dangerous and perhaps a little illogical, but what was to be done? When measuring two sources of light giving a low-level illumination, using a white test plate with either an illumination photometer or a gauge, what one wanted to know was when the white test surface had a certain apparent brightness, and unless the whole thing was to become very cumbersome, there did not seem to him to be any escape from the use of the term "apparent illumination" under the particular conditions dealt with in the paper. The only alternative seemed to be some such phrase as "illumination giving an ideal diffuser an apparent brightness of x foot-lamberts"—a clumsy alternative.

Dr. Wright had asked him for chapter and verse with regard to some of the categorical statements made in the paper concerning the absence of the Purkinje effect at small field sizes. Probably he had been a little too comprehensive when writing the word "absent" or "unnoticeable." Perhaps, after all, the evidence was not sufficiently strong to justify him in being so dogmatic, and he had better say that the effect was small enough to be negligible, having regard to the accuracy of measurement under the conditions he was considering. With regard to the continued presence of the Purkinje effect, even when the illumination was at such a level that colour could not be distinguished at all, there appeared to be some evidence for that. For instance, König's classical work showed that the spectral sensitivity curve for the eye was practically the same for all low values of brightness, including those below the limit of colour perception. It certainly seemed reasonable to think that the facts were as stated in the paper. Replying to Dr. Buckley's question regarding the size of the field, he said he thought it would perhaps not be wise to require in the specification a larger field than 5°, although a 10° field would probably give a better result.

Mr. J. S. Dow, who likewise promised to deal with the discussion more fully in his written reply, remarked on the variety of impressions formed by the

audience. It appeared that this was due chiefly to the element of correction introduced by the glasses worn, as Mr. Waldram and Mr. Maxted had suggested. The audience had commented mainly on the appearance of the screened filament, and had said relatively little in regard to their impressions of the sharpness of outline of the illuminated objects.

The President, amongst others, had, however, recorded impressions at variance with his own.

Mr. Dow stated that his own impressions were very clear and definite. At twenty feet or more the outlines of letters or other objects illuminated by pure blue-violet light became so indistinct as almost to disappear from view. He had met many people whose impressions in this respect were as vivid and definite as his own, and it seemed to be common ground that the natural eye tends to be short-sighted for the blue end of the spectrum. But the very fact that in an audience of people with "ordinary vision" there should be some who saw something quite different from that seen by others was surely extremely interesting. The experience seemed to be almost unique in illumination and photometry. In connection with other problems there were *differences in degree*, but—except possibly where colour-blind persons were concerned—there was, so far as he was aware, no similar conflict in the evidence of the senses.

He still thought that most people found it difficult to see blue-illuminated objects distinctly at a distance—though no doubt the wearing of glasses made a difference. He would not go quite so far as Mr. Bennett in preferring light from the red end of the spectrum, because the Purkinje effect rendered this so inefficient at weak illuminations, but it might be advantageous for objects which had to be identified by outline at some little distance to be illuminated by yellow or orange light.

He was interested to hear that both Mr. Waldram and Dr. Wright confirmed, in some degree, the apparent increase in effect of contrast with sodium lamps at low illuminations.

Mr. Waldram had touched on an important point in alluding to the effect of "scatter" in photometry. If this effect was so evident in such a short distance as 100 ft., its influence on the performance of sources of lights called upon to illuminate large areas, e.g., in streets and on aerodromes, might well be considerable. It must also be remembered that in some cases, e.g., motor-car headlights, the action of the scattered light itself, in forming a species of luminous haze was of importance. From this aspect he was not sure that selective action in scatter could be ignored, because in the case of an illuminant furnishing several distinct lines in the spectrum the visual effect might be magnified by the selective action of the eye. This, he thought, might influence to some extent one's impressions of streets illuminated by mercury vapour lamps.

In conclusion, Mr. Dow remarked that there was some tendency to search for methods of photometry which eliminated, or at least minimised, the Purkinje effect; for example, to advocate the use of a small field of view because more consistent results at high and low illuminations were thus obtained. It should always be remembered, however, that the attainment of such consistency meant that photometry was not fulfilling its object because such tests might lead to an incorrect impression of the comparative effect of two heterochromatic sources when used in practice to illuminate outdoor areas subtending very large angles at the eye.

Opening Sessional Meeting

The opening sessional meeting was held at the E.L.M.A. Lighting Service Bureau, 2, Savoy-hill, London, W.C.2, at 2.30 p.m., on Tuesday, October 14.

After the minutes of the last meeting had been taken as read and approved, Professor J. T. MacGregor-Morris introduced the new President (Mr. W. J. Jones), alluding to the fact of his having been a student under the first I.E.S. President (Professor Silvanus P. Thompson), to his long-standing services to the Society, and to the enterprise and enthusiasm shown by him in developing educational and demonstration work at the E.L.M.A. Lighting Service Bureau.

Mr. W. J. Jones, on taking the chair, moved a vote of thanks to Professor MacGregor-Morris for his efforts and services as President during the past session, which was carried unanimously. He referred especially to the address, comprising records of much original work on the arc, presented by his predecessor at the opening meeting in 1940, which was so fittingly held at the Royal Institution.

In accordance with custom, the President then made the award of the Leon Gaster Memorial Premium, which the Council had granted to Mr. J. G. Holmes for his paper on "The Recognition of Coloured Light Signals," read before the Society on February 11, 1941.

The President then delivered his address, which was illustrated by demonstrations and lantern slides. He recalled the aims for which the Society was founded, emphasised the necessity for co-operation with experts associated with other professions, and pointed out the peculiar importance of "the human element" in illuminating engineering. He reviewed briefly recent progress in electric lighting, dwelling upon the need for standardisation of lamps and voltage, and discussing the possibilities of fluorescent lamps and architectural lighting. He mentioned the Society's contribution to war work and the formation of committees to study lighting in connection with post-war reconstruction. Finally, he made reference to the expansion of the Society's activities through the medium of groups and centres throughout the country. The complete version of the address will appear in *The Transactions* in due course.

A vote of thanks to the President for his address and to the E.L.M.A. Lighting Service Bureau for their hospitality was moved by Mr. H. T. Young, seconded by Mr. W. R. Rawlings, and carried with acclamation.

LIGHTING AND RECONSTRUCTION

By R. O. ACKERLEY (*Fellow*)

(*Delivered on Tuesday, May 13, 1941*)

The address after the annual general meeting of this Society is usually given by some distinguished lighting engineer from overseas, describing lighting progress in his country. That procedure was not practicable this year, and I think I was responsible for the suggestion that the session should be devoted to a paper outlining the part which lighting should play in the post-war reconstruction programme. It was obviously a subject on which many people would produce many ideas, and it was therefore agreed that it should be a composite paper in the sense that as many people as possible should be asked to send their views to the secretary to be condensed and embodied in an address to be given by one individual on behalf of the Society.

When I first made the suggestion I thought that one might be able to produce some practical ideas as to those points that would require attention in any immediate emergency reconstruction, some ideas as to the planning of lighting for the long-term programme, and, finally, some flights of fancy into the lighting of the future; but I very soon found the subject so vast that if any attempt were to be made to go into detail at this preliminary stage the address would go on for days, if not weeks. On the other hand, I was at once impressed with the enormous possibilities for useful work which the Society might do in preparation for the day when reconstruction can begin in earnest, and decided to try to outline to the Society some suggestions as to the sort of subjects that might usefully be given immediate consideration: the sort of organisation that might be set up to do the work entailed. The ultimate object would be what one might call an I.E.S. Reconstruction Charter.

It will be generally accepted that lighting is a vital service in any modern community. Aesthetically good lighting can bring out all the best features of a whole street, just as much as it can affect the appearance of a single building. Bad lighting, or even reasonably good lighting, superimposed on a scheme in which insufficient facilities have been provided, may mar the effect not only by night but by day as well. Good lighting is equally essential from the safety point of view, as has been abundantly proved in our streets and factories. Finally, good lighting is an essential social amenity vitally affecting the health and welfare of the people. If this is so, then the provision of the right sort of lighting in the England that will arise from the ashes after the war is an aim which should animate us all.

The first question postulated by many of my contributors was, How can we plan the lighting of the future until we know for what sort of a world we have to plan? Will it be a world still dominated by fear and experience of war, in which all buildings will have to be designed with the question of their resistance to future bombings as a controlling factor, with all their lighting arrangements planned with a view to easy black-out? How far will the restrictions of war-time have had a psychological effect on the reactions of the public after the war? Will the relaxation of the lighting restrictions cause a reaction in the form of a demand for even more artificial light, or will it, as some people suggest, cause a kind of back-to-nature movement? All the light which the sun can give us by day and a dim religious candlelight by night. Will the regimentation of war and the temporary sinking of differences in a common cause create a psychological reaction against co-operation after the war? Will the community want to spend money on lighting and will they have the money to spend? How far will vested interests, or the desire on grounds of economy, to make use of such lighting facilities as are left undamaged, restrict any possibility of sweeping change? Last, but by no means least, are the buildings of the future going to be fundamentally different in design from those with which we are familiar? Have we got to cater for skyscrapers or all glass buildings or windowless buildings? and so on.

To some of these questions we can suggest, and perhaps even influence, the answer. The answer to the psychological questions can be influenced by suitable education, for which the Society should make itself responsible. The answer to the economic questions is, I think, clear. Whatever may be the immediate reaction to public expenditure, however shallow may be the public purse directly after the war, in the long run the citizens of Bristol and Southampton, Coventry and London, and many others, cities rich in historical associations, are going to see that their cities rise again no less beautiful and no less worthy of their pride than they were before Hitler came. As regards the use of existing equipment, this must vary from place to place, depending on circumstances. Some parts of our cities are obviously so far affected that a complete rebuilding will be almost inevitable. In other cases compromises will be required.

And for the answers to the other questions, answers which may well be "yes" in one district and "no" in another, we can only wait and see, but do not let us wait in idleness. Let us get busy making preparations on a broad and flexible scale, ready for whatever may eventuate.

Here I would suggest a few overriding principles to follow. For example, that lighting must in all cases be planned and provided for as part of the broad advance scheme of reconstruction and not left, as was too often the case before the war, to be added as an afterthought when it was too late to do justice to it. That all lighting, whether decorative or utilitarian, must be based on a proper appreciation of the physical and psychological fundamentals of good vision, that in effect they must be the outcome of applied knowledge and not of irresponsible experiment. That, provided a conception of lighting is fundamentally sound, we must not be afraid of it because it has never been done before, and equally,

unless a system of lighting has a reasonable basis of applied knowledge, it must not be adopted just because it is a novelty. That provision for artificial lighting shall be as flexible as possible, not tying a user to one class of equipment or light source only and allowing as far as possible for the adoption of new methods as and when they are proved advantageous.

If these general principles are agreed to be sound there is, in the first instance, only one way by which they can secure general adoption. That is by the closest co-operation between Lighting Engineers and the Architectural Profession. The Lighting Engineer can only give his best service to the community through and with the help of the Architect, because if the lighting arrangements are not planned as part of the general conception it may well be too late to do full justice to them when in their own good time they have to be considered. There are many factors which influence and limit the lighting possibilities. Such questions as the provision of ample space for housing lighting equipment, the co-ordination of various services such as ventilation, sprinklers, etc., with the lighting requirements (how often has one found it impossible to do justice to a lighting scheme because of the presence of other services at the place where the lighting equipment should go?) the provision of the necessary architectural features to make the most of the lighting—such as recesses to conceal equipment, projecting features on the face of a building to pick up floodlighting, shaped ceilings or coves to make the most of built-in lighting—proper provision for any signs likely to be required, and so on. A point which has been emphasised by one contributor is the tendency towards low ceilings. Low ceilings impose severe limitations on the Lighting Engineer and rule out the effective use of many forms of lighting. This should be borne in mind when considering the general plan of a building.

And while I may have appeared to refer in these remarks to the architect in his capacity as a designer of buildings, they apply equally to architects in the broadest sense of the term: town planners laying out complete cities, landscape gardeners laying out parks and gardens, and consulting engineers planning factory sites. One of my architect contributors used the word "scale" in speaking of planning a town by which I think he meant that the buildings, the streets, the general plan should all be related to the purpose which each particular district served, and in the same way the lighting should be to scale.

Let us consider some specific aspects of lighting.

First of all comes the question of lighting the roads of the new England. Many suggestions have been sent to me on this subject, some of them dealing with specific methods of street lighting, some dealing with questions of control, co-ordination, and standardisation. On the latter aspect there seems to be general agreement as to the desirability of greater uniformity of practice as between one district and another. National, county, borough, and rural or urban district authorities all seem to have a share and a responsibility, and it is often a case of too many cooks spoiling the broth. Different systems, different colours of light, are often mixed together without any apparent attempt at co-ordination, and the height of absurdity is reached when one finds the opposite sides of a single street lit by two different systems. How far would it be possible and desirable for the Ministry of Transport to lay down compulsory standards for various classes of roadway, based on the nature of the surroundings, class of road, and volume of traffic? How far can guidance be given towards standardising heights and spacings? As regard methods of street lighting have we anything to learn from experience of traffic in the black-out? Can we produce a statement of fundamental requirements relating it to different classes of highway? What are the merits and demerits of different unorthodox methods of street illumination, such as lighting by reflection off floodlighted buildings? Luminous kerbs or panels let into the street? Luminous panels let into the faces of buildings? Should we in our built-up cities do away with street lighting posts and mount illumination equipment on the buildings or on span wires stretched between them? How are we to indicate cross roads and turnings? Should all street names be illuminated and house numbers, too? (Someone suggests the latter should be a service supplied by the local supply authority at an inclusive annual rental.) Can we light shopping streets with the light escaping from shop windows? Are we to expect two-floor streets with walkways and shop windows at first-floor level and a kind of loading and parking arcade beneath? How would we light such a street? Even if we do not light our streets with light reflected off the buildings ought we not at least to see that our front gardens and building faces—all those things which go to make the street surrounds—receive some illumination? Ought we not alternatively to co-ordinate such lighting as may come from floodlighting or shop windows with the scheme of lighting in the street? How far can we educate the building owner to recognise his responsibility for the general amenities of the street in which his building stands?

Next, after street lighting, comes public amenity lighting. To what exent should all beautiful and historic buildings be floodlighted, or at least provided with facilities for installing floodlights? Should street lighting systems be provided with facilities to convert them temporarily for celebrations so that on all great occasions we can "say it with light"? Can we not instal more illuminated fountains and floodlight the statuary in our public squares or illuminate with floodlighting or other suitable means our public parks with their beautiful flowers and foliage and waters? Illumination for outdoor sports must also not be forgotten.

The place of illuminated signs in our new cities will have to receive very serious consideration, so that they become at worst a not unpleasant adjunct of the commercial world we live in, at best a definite attraction in the night life of our cities. It may well be that it will be found desirable to divide signs into two classes: those which advertise the

building on which they are placed and those of a general nature, such as the displays in Piccadilly-circus, Trafalgar-square, and Leicester-square. Control of design of the former in, at any rate, the better-class shopping streets would appear both practical and desirable. For example, signs built into the building face, showing their message in letters silhouetted against a floodlighted cove or background, may be both dignified and pleasing and lend themselves to variety both in design and colour without being garish. As regards general advertising signs, it may well be that in the city of the future they will be confined to certain suitable areas and not, as at present, be allowed to intrude in all sorts of places where they clash with their surroundings.

Now let us consider the problem of lighting the interiors of our buildings. Much has already been said of windowless buildings. For certain classes of buildings the windows to-day serve very little purpose. In most of our big stores, in our theatres and restaurants, and many other buildings the daylight rarely penetrates. Why not, then, do away with windows altogether in such buildings, thereby making control of light and heat and ventilation all very much simpler? In fact, an American writer has claimed that it is only in a windowless building that these services can be properly controlled.

The whole question of built-in lighting must be considered very fully by both architects and lighting engineers, and the correct use and design of low-surface brightness sources, with particular reference to the startling new light sources recently made available. As they are to-day these sources present amazing possibilities. How can we best use them? How can we improve them to give us even greater advantages? The question of colour in interior lighting must also be jointly examined, it being remembered that colour of light and colour of decoration are intimately related. And now that we are able to obtain an efficient light source with colour and other qualities closely simulating daylight, we should examine more fully the advantages, perhaps largely psychological, of such a light compared with those which we have had to "make do" in the past.

That there will be a demand for more and even more light may be taken as certain, I think. What alterations in our technique have we got to consider to make high illumination intensities beneficial and not uncomfortable? We must examine the relative benefits, for example, of low-surface brightness sources, indirect lighting, louvred sources, and perhaps a dozen others. In this we may be able to learn quite a lot from our friends in the U.S.A., where materially higher illumination intensities have been in vogue for some time. In this connection, too, the possibilities of new materials must not be overlooked, such as anodised aluminium, plastic and synthetic materials generally, and fluorescent substances.

Turning now to specific classes of building, there will be many which have certain definite features in common to all of that particular class; for example, the fundamental requirements of schools, public libraries, churches, art galleries, and hospitals may to some extent, each in their class, be reasonably clearly defined. Without in any way attempting to lay down a one and only way in which such buildings should be lit can we not lay down the points which have got to be borne in mind by anyone taking on the lighting of them?

In a similar manner the fundamental requirements of good office lighting should not be beyond the skill of man to state, and the elements of shop lighting, bearing in mind the comfort of the customer on the one hand and the requirements of display on the other. As regards our factories, recent legislation will at least ensure very much better lighting in the future than we have had in the past, but our war experience has shown up some very weak chinks in even what we thought was quite well-fabricated armour. I refer particularly to the psychological effect of background brightness. And on this subject of factory lighting I would again ask that consideration should be given to the question of factory design from the artificial lighting point of view. The north light construction, which is so effective in the daylight, is by no means the ideal when night comes on. Cannot some ingenious architect evolve a new form of factory construction which will reconcile the requirements of day and night lighting to the greatest advantage to both?

Last, but not least, we have to consider the home of the future. Individuality of taste and decoration must be given full play, but even here we may be able to suggest some method that will tend to bring better seeing conditions. First, the abolition of pendant points and their replacement by simple forms of built-in lighting, even in the humblest homes. Second, the provision of heaps of plug points, or, better still, as one of my correspondents has suggested, a continuous run around the room of concealed busbar which can be tapped off at any point. Such devices can be universal; and, for those who have the money to spend on something more elaborate, the possibilities of light in the home for display and decoration and practical utility, such as dummy windows where the outlook would otherwise be on to a blank wall, illuminated curtains, good lighting for mirrors, cupboards, and stairs should all be made known. As one of the many more elaborate revolutionary ideas forwarded to me I would mention a system employed by an American architect, Richard Neutra, who has lit a room by means of hooded floodlights placed above and outside the windows in such a way that no curtains are necessary at night to hide the inmates from curious eyes. The external reflection of the light source acts as a curtain in the eyes of outside observers, while the inmates can watch unimpeded everything which goes on outside. It has been impressed upon me on this question of lighting generally, and home lighting in particular, that our systems of charging for electricity need overhauling. Even the poorest person, buying his current through a slot meter, must not be discouraged by unreasonable cost from getting plenty of light. This is a social necessity. What exactly is the best methods the experts must decide, but one interesting suggestion is the universal adoption of all-in tariffs, with the standing

charge based on the amount of lighting the building should have.

What, then, can the I.E.S. do about all this? In the Articles of Association the first object of the Society is stated to be: "To promote the general advancement of illuminating engineering and the utilisation of natural and artificial light and the dissemination of knowledge relating thereto."

This being so, it is surely our duty as a body, as I am sure it is our desire as individuals, to do everything we can to ensure that only good lighting in its broadest sense is allowed in our reconstructed areas. To this end it will be our function as a Society firstly to ensure that all those concerned with selecting lighting systems realise the importance of making a right choice, secondly to give them such technical guidance as is possible to enable them to make this choice. How best can the Society do this?

As one possible way of dealing with the matter, I will suggest a programme. I suggest that the Society immediately set up committees or panels—call them what you will—to study the problems involved from two main angles: the political angle and the technical angle. It will be the function of the first committee to decide how best the services of the Society can be placed at the disposal of the community, with what authorities contact should be made and how, to what extent co-operation can usefully be secured with other technical bodies—the architectural profession stands out here, but there may be other bodies, such as branches of the gas and electrical world, associations of engineers, and so on. Then will come the contact with other cultural organisations—the Safety First Association, the Industrial Welfare Society, and others. It will also be the function of this Society to examine the ways and means of getting general adoption of good lighting principles: how far it must be done by persuasion, how far by compulsion. The Factory Act clears the way for us in factory lighting. How far can other laws and by-laws, building regulations, town-planning acts, and the like be used to enforce reasonable standards of highway lighting, to ensure dignity and decency in the use of exterior lighting on buildings, to see that adequate lighting provision is included in the erections of speculative builders, to see that the welfare of office workers receives not less attention than that of factory workers from the lighting point of view? And if suitable laws do not exist can we not get some of these points taken care of by new laws? Inevitably there will be much legislation in connection with the reconstruction programme and improvement in building standards may well be among them.

On these points I have received many practical suggestions, of which the following are typical: That building permits should not be granted unless details of the lighting proposed is submitted with the application. That public authorities should have the right in specified classes of streets to insist upon floodlighting or other approved exterior illumination being provided. That in utilitarian places where any employees are likely to be affected, such as factories, large offices, and the like, it shall be compulsory to decorate in light matt colours of not less than some specified reflection factor. Even if we cannot get the sort of standards we would suggest made compulsory we might well achieve the position already achieved in relation to factories where the I.E.S. Code is recommended officially in a Government report as the criterion of adequate lighting, and is adopted by the Service Ministries as compulsory in all key factories.

It would be the function of the other Committee, the Technical Committee, to prepare simple technical pamphlets on various aspects of lighting; pamphlets which would express the main principles involved in each problem in broad general terms, not attempting to say this particular way or that particular way is the one and only right way of doing a particular job, but setting forth clearly the requirements which must be met. This Committee might start with the preparation of a sound but simple statement of what are the fundamentals of good vision set out in practical terms comprehensible to the layman. To this end it should examine our knowledge of lighting in the light of practical experience and particularly add to our previously published store of knowledge the lessons learnt from war-time problems. The new knowledge of contrast and brightness we have gained from our low intensity investigation, the knowledge of the psychological effect of background brightness, and the practical considerations of industrial lighting we have learned in our blacked-out factories. Such a statement should not be too long, on broad lines illustrating different fundamental points from different aspects of lighting, e.g., the need to avoid excessive contrast for a working light in factory or office, the deliberate use of high contrast in commercial display. Such a statement might attempt to put foot-candle in their right place in relation to quality and distribution of light.

Of the many other general subjects already mentioned I would suggest for early consideration the proper use of low surface brightness light sources, the fundamental requirements of built-in lighting, and the points to be specially watched when installing high intensity illumination, and so on. Other priority subjects would be street lighting, public amenity lighting, and the requirements of special buildings, such as libraries, hospitals, art galleries, and churches, and—dare I mention?—railway stations. These pamphlets should be prepared quickly, and the Committee should not be allowed to drag on in order to get the last word agreed on some arguable point. There are many points on which there would be general agreement. Publish them quickly and let the rest follow. A pamphlet on the fundamental requirements of industrial lighting published recently by the N.I.E.L.S. might be taken as one possible model. As a member of the Committee who drafted that pamphlet I can testify to the ease with which unanimity on all the points covered was obtained. The pamphlet has been widely praised as giving useful guidance. I suggest that just as useful guidance could be given on many other aspects of lighting. And if we get something done quickly and get it distributed to the right authorities, however incomplete the work may be, it will serve partly as a practical guide within its limits, partly as a means to stimulate further inquiry; and it may well be that, as with the

A.R.P. lighting at the beginning of the war, we shall soon find ourselves being inundated with new problems.

We must consider what part research can play in this work. For our initial work we cannot wait for fresh research. The immediate requirement is, I suggest, to make known the work already done, the knowledge already acquired, and relate it to typical practical applications. But as new specific problems arise or as time allows us to go deeper into the old problems, there will be much for the research worker to do. If the I.E.S. are to organise and co-ordinate this work, should some attempt be made to set up an Illumination Research Association to take the place of the now disbanded Illumination Research Committee of the Department of Scientific and Industrial Research?

I have only just mentioned, for the first time, the work of the Society in connection with A.R.P. Lighting, but I want to close by referring to that work as an inspiration for the work I am now suggesting. Prior to the war the standing of the Society as an impartial body with the full weight of technical knowledge and achievement behind it was too little known outside the circle of those intimately connected with lighting. Thanks largely to the initiative and persistence of our President at that time the Society was able to have its services accepted by the Government as official advisors on all A.R.P. Lighting problems. At first one or two specific questions were put up to the Society, and when it delivered the goods, and delivered them quickly, more and more was asked of it. As a result of that work the Society has undoubtedly gained prestige as well as the satisfaction of having been of some real service to the community. But the gaining of that prestige and the performing of that service involved a lot of real hard work freely given by members of all classes. I want to conclude by suggesting that the problem of lighting for the future is one just as worthy of our full support, and certainly one very much more after our hearts.

It may be argued that we are all too busy winning the war to be able to give time to preparing for the peace, and that we should wait till peace seems nearer. This might well be a fatal policy which would result that in lighting, at any rate, having won the war we should lose the peace. On at least two separate occasions the Prime Minister has told us the end may well come sooner than we now have the right to hope. The Prime Minister has proved himself a very good prophet so far. I do not take his words as meaning that the end of the war is in sight, but I do take them as meaning that when the end comes it will probably come very suddenly. Let us, therefore, not relax our efforts to win the war, but be prepared to put the same extra intensive effort to the reconstruction problem as we put to A.R.P. Let us do it now, and we shall then, I am sure, be able to feel we are contributing something towards the better world which we all hope will come out of the present tribulation.

DISCUSSION

Mr. PERCY GOOD, in opening the discussion, congratulated Mr. Ackerley on his address. Referring to Mr. Howard Robertson's remarks at the luncheon, he stressed the importance of close contact between the lighting engineer and the architect. Owners of buildings had responsibilities and should see that they were decorative externally and effectively lighted. Assistance to traffic was not the sole purpose of street lighting. There were amenities to be considered, as in the illumination of fountains, parks, and gardens. The study of these problems should provide relief from war work. Early action was, however, necessary.

Mr. W. GOODESMITH, as an architect, concurred that the planning of lighting in buildings should receive attention at an early stage in the design. Minimum requirements of artificial lighting, which were just as important as natural lighting, should be incorporated in building regulations. As an instance of co-operation in technical matters he mentioned important work recently done on acoustics of buildings.

Mr. W. J. JONES emphasised the need for co-operation with the architectural profession and for quick action. He referred to the lighting of government and public buildings as a field where much might be done, mentioning the cases of churches and schools. A report on school lighting had been issued by a committee of the Society, which had, however, as yet devoted too little attention to domestic lighting. The resources of the British Standards Institution would be of great value in dealing with reconstruction problems.

Mr. REGINALD STAMP, who referred, incidentally, to I.E.S. researches on cinema lighting, urged the need for speed, combined with reasonable consideration of economy and simplicity. Very many buildings would have to be erected after the war. There was an opportunity, therefore, of incorporating in the Building Acts some requirements in regard to lighting. He agreed that lighting should be considered in connection with architectural developments, which might be on a revolutionary scale.

Mr. F. C. SMITH, who supported Mr. Ackerley's suggestion that a committee should be appointed to study these problems, stressed the importance of consideration of lighting in connection with the lighting of homes for the people. Mr. RALPH TUBBS pleaded for research on the relation of lighting to town planning, and Mr. L. G. APPLEBEE suggested the compulsory provision of illuminated numbering for houses and business premises.

Mr. R. O. ACKERLEY, after briefly dealing with remarks of previous speakers and the general desire expressed that attention should be devoted to these problems, moved a formal resolution that the Council be requested to take such action as they deemed necessary to initiate the immediate study of reconstruction problems. This was seconded by Mr. D. W. DURRANT and was declared carried unanimously.

SESSION 1941—1942

THE I.E.S. COUNCIL.

President :—W. J. Jones, M.Sc., M.I.E.E., F.I.E.S.

Vice Presidents :—R. O. Ackerley, F.I.E.S., H. Buckley, F.Inst.P., F.I.E.S., E. J. Stewart, M.A., B.Sc., F.I.E.S.

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Hon. Treas. :—E. W. Murray. *Hon. Sec.* :—J. S. Dow.

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*In addition all Past Presidents of the Society, and the Chairman of recognised Centres (during their term of office) are *ex officio* Members of Council.

Committees.

General Purposes Committee:—W. J. Jones (*President*), J. S. Dow (*Hon. Secretary*), E. W. Murray (*Hon. Treasurer*), R. O. Ackerley, H. Buckley (*Vice-Presidents*), F. C. Smith, Professor J. T. MacGregor-Morris (*Past-Presidents*). Co-opted Members: A. Cunningham, S. English, E. Stroud, E. J. Stewart.

Papers Committee:—H. Buckley (*Chairman*), C. E. Greenslade, W. M. Hampton, R. Maxted, E. B. Sawyer, F. C. Smith, W. D. Wright.

Lighting and Reconstruction Committee:—R. O. Ackerley (*Chairman*), Dean Chandler, S. English, Percy Good, W. J. Jones, C. C. Paterson, F. C. Smith, J. W. T. Walsh, Sir Duncan Wilson.

President, Honorary Treasurer, and Honorary Secretary *ex-officio* members.

(N.B.—The President, Hon. Secretary, and Hon. Treasurer are *ex-officio* members of all committees.)

Recognition of Groups and Centres.

The Council has approved the application of members in the North-Eastern area to constitute a new Group, and Officers and Committee have been appointed, as indicated in the next column.

The Council has also approved the requests of the Centres in the North-Western, Midland, Scottish, and Nottingham areas for formal recognition, so that all the existing five Centres are now placed on the same footing.

I.E.S. CENTRES AND GROUPS.

North Midland Centre:

Chairman: W. Hetherington. *Vice-Chairman:* E. C. Walton. *Hon. Secretary:* W. F. Pogson. *Hon. Treasurer:* W. H. Harris. *Committee:* L. Bridgewood, J. G. Craven, F. Firth, J. W. Howell, T. C. Holdsworth, W. I. Ineson, A. Kelso, R. O. Seville, A. Southern, J. W. Whitaker. *Hon. Social Secretary:* H. Peters. *Hon. Development Secretary:* J. H. Mollan. *Hon. Auditors:* E. Dunn, G. Casperson.

North-Western Centre:

Chairman: J. Taylor. *Vice-Chairman:* W. H. Smith. *Hon. Secretary:* Alan H. Owen. *Hon. Treasurer:* J. A. Somerset. *Committee:* J. N. Bolt, W. M. Fisher, C. M. Frobisher, N. C. Hodson, C. F. Hurd, John Swarbrick, D. M. Thompson, H. C. White.

Midland Centre:

Chairman: P. J. Watson. *Hon. Treasurer:* F. F. Middleton. *Hon. Secretary:* C. J. Allderidge. *Committee:* F. Roper, F. C. Johnson, H. S. Allpress, F. C. Dain, W. J. G. Davey, P. Hartill, J. G. Holmes, P. Hulse, A. J. Pashler. *Ex Officio:* F. S. Ette, W. M. Hampton and Howard Long.

Scottish Centre:

Chairman: E. J. Stewart. *Vice-Chairman:* J. H. Scott. *Hon. Secretary* and *Hon. Treasurer:* M. W. Hime. *Committee:* J. Dickson, T. Gavin, F. Hailstones, E. M. Hood, S. B. Langlands, D. MacFarlane Macleod.

Nottingham Centre:

Chairman: M. Wadeson. *Hon. Secretary:* C. S. Caunt. *Committee:* J. C. Charity, A. C. Collard, A. Hacking, G. C. Hadfield, A. G. Kidd, W. Jackson, G. D. Johnson, E. G. Phillips, T. E. S. Thwaite.

South Wales Group:

Chairman: Edward Jones. *Hon. Secretary and Treasurer:* S. G. Turner. *Committee:* Prof. T. David Jones, C. S. Chubb, T. E. Alger, R. J. Auckland, J. H. Dinham, D. C. James, A. E. Luen, C. J. Page, T. Scott Harrison, W. H. Stone, V. G. Wackrow.

North-Eastern Area Group:

Chairman: S. I. Ellis. *Hon. Secretary:* Stuart D. Lay. *Committee:* E. C. Lennox, J. S. McCulloch, J. Mitchell, W. N. Smithson, J. Stewart, S. Tillotson, J. E. White.

Forthcoming Meetings

Nov. 11th. Mr. H. C. Weston on **Industrial Lighting in Relation to Reconstruction.** (*Sessional Meeting to be held in the Lecture Theatre of the E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, London, W.C.2.*) **2.30 p.m.**

Nov. 6th. Dr. J. H. Saxby on **The Physiological Aspects of Lighting.** (*Meeting of I.E.S. South Wales Group, in the Lecture Theatre of the Medical School, University College, Newport-street, Cardiff.*) **3.30 p.m.**

Nov. 10th. Dr. W. M. Hampton on **The Manufacture of Glass.** (*Meeting of I.E.S. North Midland Centre, at the Great Northern Station Hotel, Leeds.*) **3 p.m.**

Nov. 13th. A series of **Short Papers on Lighting Problems, etc.** (*Meeting of I.E.S. North Western Centre, at the Manchester School of Technology, Sackville-street, Manchester.*) **2.30 p.m.**

I.E.S. Fellowship.

The following applications for Fellowship have been accepted by the Council:—

Higgins, A. G. .....Gas Efficiencies, Ltd., Roan Street, Greenwich, LONDON, S.E.10.

Hoskins, C. A. .....100, The Walk, Potters Bar, MIDDLESEX.

Phillips, C. W. M. ...The British Thomson-Houston Company, Ltd., Bridle Path, Watford Junction, Watford. HERTS.

Additions to List of Members.

In accordance with the procedure outlined in the Revised By-Laws the following applicants have been duly elected by the Council to Membership in the Society and their names have been added to the list of members *:—

CORPORATE MEMBERS:—

Barlow, C. J. B. .....Warrington Electrical Company, Ltd., 129-131, Bridge Street, WARRINGTON.

Batey, R. H. .....14, Preen Drive, Acklam, MIDDLESBROUGH.

Bejnowski, A. .....522, Sauchiehall Street, GLASGOW, C.2.

Bell, R. H. .....74, Kelvin Grove, NEWCASTLE-UPON-TYNE.

Bird, W. J. .....10, Beech Hill Road, Wylde Green, BIRMINGHAM.

Brown, A. S. .....25, Ashtrees Gardens, Low Fell, Gateshead, Co. DURHAM

Collis, S. F. .....Sun Electrical Company, Ltd., Carliol Square, NEWCASTLE-UPON-TYNE.

Cross, W. .....7, Ridley Place, NEWCASTLE-UPON-TYNE.

Etchells, H. .....61, Chesnut Drive, Sale, CHESHIRE.

Fitzgerald, W. .....10, The Poplars, Gosforth, NEWCASTLE-UPON-TYNE.

Fletcher, L. .....36, Vennard Gardens, GLASGOW, S.1.

Hewling, R. J. .....Lynwood, The Hills, Skelton-in-Cleveland, SALTBURN-BY-THE-SEA.

Hoult, S. J. M. .....203, Haslucks Green Road, Shirley, BIRMINGHAM.

Jenkins, R. .....Electricity Department, Electric Buildings, 112, High Street REDCAR.

McCraith, J. K. .....British Thomson - Houston Company, Ltd., MIDDLESBROUGH.

Meeks, W. K. .....6, Rutland Grove, Hammersmith, LONDON, W.6.

Morgan, H. G. .....44, Hendrefoilan Road, SWANSEA.

Redshaw, W. .....Myrtle House, New Road, Crook, Co. DURHAM.

Rivlin, J. .....20, Wensley Drive, LEEDS, 7.

Sheldon, J. W. .....3, Regent Place, RUGBY.

Sloan, J. C. .....53, Thane Road, GLASGOW, W.3.

Smithson, W. H. T. ....31, Devonshire Place, NEWCASTLE-UPON-TYNE.

Spencer, H. V. .....60, West Road, Spondon, nr. DERBY.

Satchwell, C. .....“Abrigo,” Colishill Road, Marston Green, WARWICKSHIRE.

Sawkins, D. J. .....Highways, Edward Road, Walton St. Mary, Clevedon, SOMERSET.

Smithson, W. N. .....20, Flora Avenue, DARLINGTON.

Tucker, R. E. .....Juneland, Bathampton, nr. BATH.

Turner, F. F. .....Philips Lamps, Ltd., The Handysidis Arcade, Percy Street, NEWCASTLE-UPON-TYNE.

Walker, G. N. .....1, Little Hardwicke Road, Alderidge, nr. WALSALL.

Webb, F. H. .....Craignethan, Bridge Park, Gosforth, NORTHUMBERLAND.

Wheeler, C. S. .....Grove Mansions, 91, Burton Road, Derby.

Winfield, F. C. .....“Woodlands,” Rowlands Gill, Co. DURHAM.

Winterbottom, J. G....20, Brookfield Drive, Timperley, CHESHIRE.

ASSOCIATES:—

Clarkson, D. G. .....20, Swinbourne Gardens, Whitley Bay, YORKS.

Johnson, L. L. .....1, Brocastle Road, Whitechurch, CARDIFF.

Powley, G. .....16, Alcombe Road, NORTHAMPTON.

Stott, G. L. .....522, Walmersley Road, Bury, LANCS.

* In accordance with the present procedure the names of all applicants for membership are published in THE TRANSACTIONS as soon as such applicants have received approval of the Council and the subscription for the current year has been duly paid.

Changes of Address, etc.

Members are particularly requested to keep the Honorary Secretary informed of changes of address, and also to notify him in the event of their taking service with the Forces in order that this may be noted in the register.

Transference from Country Membership to Corporate Membership.

Ainscow .....17, Branksome Avenue, Prestwich, LANCS.

Baker, R. G. .....32, Ranelagh Grove, NOTTINGHAM.

Collard, A. .....Rotherfield, Mapperley Hall Drive, NOTTINGHAM.

Cresswell, J. E. .....Dovercourt, 6, Eton Road, West Bridgford, NOTTINGHAM.

Douglas, J. T. .....41, Granville Drive, Forest Hall, NORTHUMBERLAND.

Fieidling, C. .....16, Hall Road, HEBBURN-ON-TYNE.

Field, P. L. .....British Thomson - Houston Company, Ltd., 1301 Stratford Road, BIRMINGHAM.

Glover, W. S. .....c/o. Stephen Glover & Co., Tudor House, WALSALL.

Harrison, W. J. .....c/o. Electric Supply Department, 14, Dale End, BIRMINGHAM.

Harvey, H. Wade .....Clovelly, 149, Church Road, Penn Fields, WOLVERHAMPTON.

Heydon, V. .....197, Lichfield Road, Four Oaks, nr. BIRMINGHAM.

Hurd, C. F. .....26, Shepley Drive, Hazel Grove, CHESHIRE.

Jackson, W. H. .....83, Wilford Lane, West Bridgford, NOTTINGHAM.

Lennox, E. C. .....North Eastern Electric Supply Company, Ltd., Carliol House, NEWCASTLE-ON-TYNE.

Macartney, H. .....Woodville, 64, Wilmslow Road, Cheadle, CHESHIRE.

Mayall, A. W. .....61, Moor Street, BIRMINGHAM.

McCulloch, J. S. .....c/o. R. W. Gregory & Partner, Pilgrim Street, NEWCASTLE-ON-TYNE.

Metcalf, E. .....Haulfre, Wynyard Close, SALE.

Morris, A. J. .....Cheltenham and District Gas Company, North Street, CHELTENHAM.

Sanderson, J. B. .....Meden Bank, Pleasley Vale, MANSFIELD.

Shaw, S. .....32, Green Bank Avenue, Hall Green, BIRMINGHAM.

Slater, S. .....Braymont, Norton Lane, Grimes Hill, Wythal, nr. BIRMINGHAM.

Smith, W. H. .....Rylston, Alkrington Green, Middleton, LANCS.

Somerset, J. A. .....1, Bank Street, MANCHESTER 15.

Stanley, D. .....18, Regent Street, NOTTINGHAM.

Taylor, P. S. .....Midland Foundry, Sandiacre, nr. NOTTINGHAM.

Thorpe, E. G. .....20, Whitefields Road, Solihull, nr. BIRMINGHAM.

Thorpe, F. W. .....20, Whitefields Road, Solihull, nr. BIRMINGHAM.

Truman, H. F. .....40-42, Bridge Street, WALSALL.

Tye, R. M. .....52, Combemartin Road, Southfields, LONDON, S.W.18.

Tyldesley, E. .....Cryselco, Ltd., 11, Albert Square, MANCHESTER.

Underwood, P. S. J. ...6, Forest Avenue, Forest Hall, NORTHUMBERLAND.

Wainwright, J. H. ...Halesowen Gas Company, Gas Offices, Halesowen, WORCESTERSHIRE.

Welsh, J. .....The Edison Swan Electric Company, Ltd., 167A, St. Vincent Street, GLASGOW.

Lighting and Post-War Reconstruction

In his presidential address, delivered before the society on October 14, Mr. W. J. Jones, referred to the committee, under the chairmanship of Mr. R. O. Ackerley, appointed by the council to investigate Lighting and Post-War Reconstruction. Sub-committees have been formed to deal with such problems as the lighting of streets and outdoor areas, schools and public buildings, offices and factories, etc., and to study existing laws and regulations bearing on illumination.

As this work develops it will doubtless make further calls on the services of members of the society. The council would therefore be glad to hear from any members in a position to assist—particularly those with specialised knowledge of certain aspects of illuminating engineering.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—"Trans. Illum. Eng. Soc. (London)."

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LIGHT AND LIGHTING—A FORWARD OUTLOOK

PRESIDENTIAL ADDRESS

By W. J. JONES, M.Sc., M.I.E.E. *(Fellow)*

(Read on Tuesday, October 14th, 1941.)

It is convenient, as a starting point to this address, to adopt the name of the Journal of the Society which lends itself readily to a broad survey of the Society's work.

The declared aim of the Society, founded in 1909, more than thirty years ago, was "to promote the general advancement of illuminating engineering and the utilisation of natural and artificial light, and the dissemination of knowledge relating thereto."

This indicates a very wide conception of the field covered by the Society. In the Articles of Association it is clearly laid down that the Illuminating Engineering Society is neither a Society of Illuminating Engineers nor is it solely concerned with illuminating engineering. So at the outset of my address I would beg professional lighting engineers, especially as we now have within our ranks the class of members distinguished as Fellows, to recognise that the technical requirements of lighting form but part of a general background. Of this background the view points of other experts form an essential part.

The usefulness or otherwise of light depends on the satisfaction the eye receives in being able to see clearly and/or the presentation of brightness contrasts giving architectural form, and last but not least a sense of well-being.

Even before 1939 we were being led to attach more and more importance to such considerations, but black-out conditions associated with war have brought home still more directly the importance of the psychological aspect of light and lighting. It may well prove that our future approach to many lighting problems as far as adequacy and suitability are concerned, will be dominated by the consideration of the sense of well-being. It is certain that the great cheapening in the cost of light enables it to be used in greater abundance, and in assessing the economics the tonic atmosphere of good lighting may ultimately predominate.

From its inception the Society has enjoyed the support of men in widely different branches of art and science. The Society has much to gain from having members with medical and artistic leanings, and in the expansion of the Society's membership greater efforts should be made to attract to its ranks those interested in Arts and Sciences, and in particular those responsible for health and eyesight preservation, whose aid will be invaluable in connection with the problems we shall be called upon to solve in the future.

The Human Element

It is also well to recognise that the "human element" plays a much greater part in illuminating engineering than in some other fields of engineering. The untechnical man-in-the-street would be going beyond his knowledge if he insisted on specifying the nature of a gas engine or an electric motor, or its performance. But he may well hold quite definite views in regard to lighting fittings, which if sometimes imperfectly expressed, may be found to have a solid basis of reason behind them. We have also to recognise and bear with the human element in appraising the value of good lighting, for on the education of the public (especially those responsible for expenditure on lighting) to appreciate this value depends our success.

Apart from this we must recognise that there is much to be learned from the special view point of the user of light, who may not know much about the technicalities of lighting, but probably understands what he desires this light to accomplish. The recognition of this fact is quite consistent with a high regard for expert knowledge on lighting problems.

Much of the future of the Society depends upon the lighting man with practical experience for, as in most other spheres, theory must be tempered with practice. I for one hope that in our educational facilities we shall retain the practical view point which was taught alongside theory in our technical institutes of a decade or so ago.

Practice and Theory

As an example may I quote the life of an electric lamp.

In an experimental laboratory the relation between life and efficiency may be readily calculated and verified—a reduction in efficiency will increase the "rack" life of an electric incandescent lamp. This is true of laboratory conditions, but is not necessarily so in practice. A classic investigation of this nature dealing with the performance of miners electric lamp bulbs showed that an increase in efficiency did not greatly reduce the service life of the bulb. It is certainly equally true when dealing with household

lamps, for the manufacturer has no control over the manner in which the lamp will be used, has no control over the voltage, vibration (to say nothing of the tender mercies of "Mary Ann" or the cleaning squad).

Do not let it be imagined that these remarks are intended to depreciate the value of the theorist; rather are they intended to draw attention to the fact that laboratory results may require to be placed in proper perspective before acceptance in practice.

In the early days of the Society our insufficient knowledge of illuminating engineering gave rise to the suggestion that illuminating engineering is an art and not an exact science. One gained the impression that in many quarters this served as an excuse for ignorance. During recent years, however, the situation has greatly changed, and there are fewer subjects in which we have such a plenitude of facts, but in which it is vitally important that the facts be placed in proper perspective.

Electric Lamps.

It will no doubt be expected that the author should devote some part of his address to the subject of electric lamps, and it is therefore proposed to dwell on four main phases of the subject:—

(1) The growth and the demand for electric lamps.
(2) Problems affecting electric lamp development.
(3) The advent of fluorescent lighting.
(4) A speculation into the future.

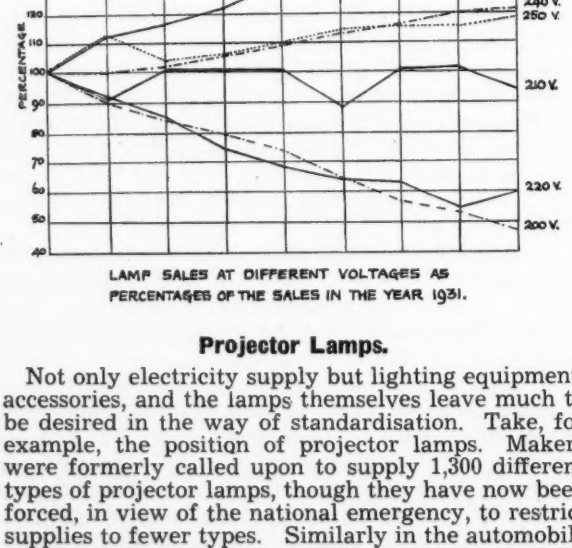
In 1922 only 1.3 millions of premises in this country were connected to electricity supply mains. In 1939 the position had changed remarkably, so that some 8 million out of a total of 12 million premises were already lighted electrically, and the consumption of electric lamps per capita during the same period increased from 0.42 to 1.75 lamps per capita per annum. It may be wondered why lamps per capita have any significance? Taken with the fact that the average wattage of lamps used in this country (70 watts) is higher than elsewhere (save the U.S.A. and South Africa (73.5 watts)), it appears that consumption of electricity for electric lighting per capita has increased over 400 per cent. in this period. This is accounted for by the increased number of lighting points throughout the country, larger lamps, and, equally important, more extended hours use per annum. The estimated present consumption of electricity for lighting purposes in this country approximates 5,400 million units per annum.

Voltage.

Lack of standardisation is still one of the bugbears of electric lamp manufacturers. At present 87.44 per cent. of lamps sold are for voltages between 170-260 and 8.79 per cent. are for voltages between 100-130. Apart from the tendency to use fewer lower voltage lamps (100-130), the gravitation towards 230 volts is most marked, and there is a reduction in 200-220 volts, but the persistence or actual increase of 240 volts and 250 volts is a hindrance. I believe the Society should lend its full support to change-over plans to making 230 volts the only standard lighting voltage in this country, and to ask that this be made a matter of urgency in post-war reconstruction.

PERCENTAGE OF LAMPS AT VARIOUS VOLTAGES.

Volts.	Percentage.
100-130	8.79
170-260	87.44
200	6.68
210	6.98
220	7.23
230	38.43
240	16.44
250	9.93



LAMP SALES AT DIFFERENT VOLTAGES AS PERCENTAGES OF THE SALES IN THE YEAR 1931.

Projector Lamps.

Not only electricity supply but lighting equipment, accessories, and the lamps themselves leave much to be desired in the way of standardisation. Take, for example, the position of projector lamps. Makers were formerly called upon to supply 1,300 different types of projector lamps, though they have now been forced, in view of the national emergency, to restrict supplies to fewer types. Similarly in the automobile world, much inventive genius appears concerned with devising reasons for using non-standard products. Such non-standardisation can only mean uneconomic production, wasteful distribution, and the services of skilled workers which can be better used for initiating progress of a more lasting character.

Fluorescent Lamps.

Several members of the Society (Mr. J. N. Aldington, Mr. L. J. Davies, Dr. C. C. Patterson and others) have provided the Society with valuable contributions leading up to the introduction of fluorescent lamps, so the writer proposes to confine his remarks to their use as lighting units. These lamps may well be described as the outstanding novelty introduced since the outbreak of war. There is no need to recall

the special characteristics of these lamps—their high efficiency, low brightness, and resemblance to daylight—which have made them so acceptable in industry.

The United States led the way in 1938 in the production of fluorescent tube lamps, which took the form of 15-watt 18-in. lamps of white and various colours, and the outbreak of war found British lamp-makers ready to embark on the development of this form of lamp. As it was known that lamps approximately 5-ft. long had an inherently greater efficiency compared with the smaller types, British manufacturers starting by introducing 5-ft. 80-watt fluorescent lamps. This would appear to have been a wise decision, as American practice is gravitating towards the use of longer lamps, especially due to their present preoccupation on output from factories.

After the war the field available will be much wider, and modifications of the existing standard lamps, adapted to decorative display and other special purposes, will be available. They will sweep the board for lighting showcases in shops. Amongst other developments which may be foreseen are the introduction of a range of units in different sizes, down to quite small types, and affording coloured light in remarkable variety. The low brightness of these lamps will encourage their introduction into lighting schemes as decorative objects—indeed, the boundary between the functions of decoration and furnishing illumination may well become much less defined than at present.

With fluorescent lighting, levels of 20 and 30 ft.c. will be commonplace in offices and shops, while for industrial work illumination of 40, 50 and even 100 ft.c. will be an everyday occurrence.

Ward Harrison in the July issue of "Illuminating Engineering," the journal of the Illuminating Engineering Society of America, contributes a valuable article on "Fluorescent Luminaires" and rightly points out that the new light source will inspire new designs of fittings and new lighting technique. Our experience in this country of architectural lamps should materially help us in the design of lighting fittings for use with fluorescent lamps. On account of their low brightness some lighting installations will use bare lamps, especially in exhibitions and when used in lofty positions but by and large carefully designed fittings will be required for their general application in factories, shops and offices.

Ward Harrison suggests that fluorescent lamps space 1 ft. apart will provide 275-375 ft.c. according to the proportions of the room, and comments that the higher the foot-candles the more comfortable the illumination is likely to be.

The Author's experience is in accord with Mr. Harrison's. Fluorescent lighting makes it possible for eyes to use effectively artificial lighting levels which begin to approximate those of daylight itself. This is not generally true of filament lighting after 40-50 ft.c. are passed.

A Speculation.

The ideal lighting installation is probably one which permits light to be varied in intensity, a colour change to suit all moods and conditions, and last, but not least, the use of a light source which may be moved where it is wanted without let or hindrance.

Recent lamp developments have gone far in these directions—at a touch of a switch more or less light may be obtained, while the fluorescent lamp opens up possibilities of colour variation.

Flexibility of the installation to enable the position of light sources to be changed without the inconvenience of flexible wires is still a problem worthy of concentrated consideration of the installation section of the lighting industry. Even its partial solution may involve radical changes in building details, and in any event requires the joint efforts of architects, builders, and the lighting industry.

Architectural Lighting.

Such developments as those noted above will doubtless give a great impetus to the use of light for display and for decorative effects, and should encourage further experiments in architectural lighting.

The advent of architectural lighting, more properly called "light architecture," was initially somewhat embarrassing to the illuminating engineer who for a time criticised the attempts of others to use light as a medium with architectural significance. In this work the architectural profession has played a leading part by educating the public in the use of new and interesting forms of light.

It is true that early experiments in light architecture were crude and of fugitive interest, but the principles remain and are fundamentally sound in the presentation of form, whether by daylight or artifical light. Indeed, the writer is so convinced that architectural lighting in its widest sense is sound that he believes the day is not far distant when architects must be prepared to define broadly the brightness contrasts they expect and the tone level of the brightness.

It is already practical politics for the lighting engineer to reproduce in his lighting scheme the exact contrasts shown on an architect's wash drawing. If things come out wrongly in such circumstances it will be the architect who is to blame if he fails to examine his scheme at the appropriate brightness level. Where brightness contrasts greater than that shown on the drawing are required he should have recourse to the use of transparencies.

The illuminating engineer has occasionally been criticised by artists and architects for attaching undue importance to tools and implements. It has been argued that a lighting scheme would no more be judged in terms of foot-candles than a picture is assessed by the quality or quantity of paint used. It is true that the ultimate test of the success of a lighting installation is necessarily based on an appeal to the eye, but calculations of foot-candles and brightness are the essential steps on which a pleasing visual impression is produced. Moreover—if one may pursue the analogy—the great artists of the past were by no means indifferent to their tools. The old masters paid scrupulous attention to their paints,

brushes, and canvas, uniting craftsmanship with artistic perception.

Services of the Lighting Industry.

The last twenty years or so has witnessed a much closer contact between academic, professional, and trade organisations. Our Society is fortunate in having such a close connection with industry, and would be wise to cherish this relationship.

The great electricity and gas industries have well-equipped laboratories, founded on the high standards of the N.P.L., and these laboratories have been responsible for a great volume of original work, some of which may well rank as classical within its special sphere. The work of these laboratories is respected and accepted by Government and educational authorities alike. This is as it should be, for the personnel within industry has at least as good academic distinctions as those outside.

Much of the research work conducted by such laboratories is being included in papers read before scientific societies, including our own, and the fact that so much valuable information is thus being made generally available, in the interests of science, should be set to the credit of the organisations concerned.

The lighting industry has also been helpful in other ways. We are now far from the time when all that was expected of a firm was that it should issue a catalogue giving particulars and prices of its wares, and it may be pointed out that the volume of purely educational material published has been steadily growing during recent years. Apart from the regular additional publications of the organisation with which the writer is associated, mention should be made of the recently issued "Modern Factory Lighting," which won deserved recognition; and likewise of the tendency of leading firms in the lighting industry to issue up-to-date specialised handbooks. Publicists have on the one hand to deal with the general public, where it is necessary to confine attention to one or two facts at a time, emphasising these facts in a simple manner many times. At the other extreme, publicity departments present technical matters to a wide group of scientists and technicians of various interests. In meeting the requirements for public and technicians alike, not always at the same time, publicists have played a full part in lighting education during recent years.

Contribution to War Effort.

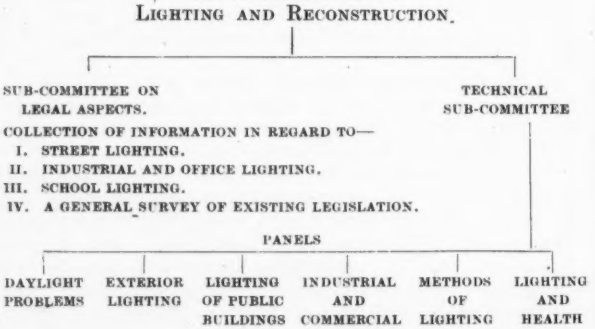
When the lighting industry is free to tell of its efforts during war-time, it will be found that its record of achievement is second to none. The Society has played a leading part in assisting the Ministry of Home Security on lighting problems associated with civil defence. A joint committee under the chairmanship of Mr. Percy Good has examined and reported upon a very large number of such problems; and twenty-four sub-committees have been at work using the services of some 100 members of the Society. They have studied the behaviour of the eyes at very weak illumination, devised new measuring apparatus (gauges) checking illumination equivalent to weak starlight, have designed new fittings, signs, etc., for use in these dim conditions. Of outstanding importance was the standard *war-time street lighting* (synthetic starlight). The researches of the Society into the visibility of objects viewed from above are being continued. The committee would be prepared with suggestions for the alleviation of the black-out, when the time is considered ripe by the authorities.

Post-war Reconstruction.

The Government interest in lighting matters during recent years culminated in February last by the Ministry of Labour making mandatory requirements for lighting in factories and workshops. Many of us believe that this step taken by the Ministry of Labour and National Service is but the forerunner of similar legislation covering other walks in life.

It seems inconceivable that this country will be content to leave workers of any kind to work under unsuitable lighting conditions, and it would be folly in post-war reconstruction to perpetuate the bad lighting of pre-war days.

In other words, planning must enter into lighting for all purposes, and the Society through its Reconstruction Committee will be playing a very full part in influencing Government and public opinion. Planning for lighting must consider the requirements of the future as well as the immediate present, so that in any installation its expansion or its modification will be a matter of relative simplicity. Already the Society's Reconstruction Committee, under the chairmanship of Mr. R. O. Ackerley, has set up sub-committees to deal with such problems as the lighting of streets and outdoor areas, schools and public buildings, offices and factories, etc., and has instituted an inquiry into existing laws and regulations bearing on illumination. One task before the Committee will be the preparation of a series of brief pamphlets setting out our aims in connection with these various reconstruction problems.



As this work develops it will evidently make further calls upon the services of members of the Society. We should therefore like to hear from any members who are in a position to assist such committees—and would like to do so—and particularly

from those with specialised knowledge of certain aspects of illuminating engineering.

In this work we must co-operate with many other bodies not only in the electrical and gas industries but with those primarily responsible for the advance planning of buildings and the assessment of costs. Architects should plan lighting in advance, and quantity surveyors must be given new percentages to replace the meagre sums allowed for lighting at the present time. It is not uncommon to find lighting starved because the quantity surveyor has failed to allow sufficient for a reasonable lighting installation, and as the lighting is usually the last feature to be incorporated in the building it often suffers further cutting when overall economies become necessary.

Expansion of the Society.

The Society has now reached a critical stage in its career. Its original membership of eighty now approaches 1,000.

The Society in 1938 arranged no fewer than sixty meetings, general, local, and sectional. When peace comes again this side of our work must increase, but in the meantime it is worthy of note that even under war conditions nearly half this number of meetings were held last session.

I am glad to note that, according to the records of meetings so far arranged, this total is likely to be at least equalled and probably exceeded during the coming session.

During the past year the Society has formulated its policy in regard to local centres. By the time these words are spoken we expect to have in full operation five fully recognised centres. We hope, in course of time, to see an I.E.S. centre in all important towns throughout the country. Why not fifty I.E.S. centres?

One step which should aid towards the attainment of this ideal is the formation of " groups " in districts where only a small nucleus of members exists, so that meetings may be initiated on a small scale and new adherents secured, until ultimately the local membership is strong enough to apply for recognition as a fully recognised centre. The first of these " groups " in the South Wales area, although only formed quite recently, is now in full operation. The formation of a second group in the North-East of England has been initiated still more recently; the creation of a third group in the vicinity of Bristol and Bath is now being considered.

All these activities so far have been kept together by an incredibly small staff led by our hon. secretary, Mr. J. S. Dow, who, on the platform and with pen, has proclaimed the work of the Society since 1909. The task would naturally be impossible but for the generous help of members of the Society in many ways, and in particular the efforts of officers and committees of groups and centres. In the future we must strengthen our organisation. We must find more income, and should increase our membership to the 2,000 mark with the least possible delay.

In the meantime we are encouraged by several remarkable facts. In spite of the stresses of war, the membership of the Society has been maintained and the income more than maintained. The proportion of corporate members is becoming continually greater. The Society has successfully negotiated the delicate and difficult operation of founding the distinction of fellowship, not as a condition of membership—for the Society remains open to all interested in its aims and objects—but as a recognition of those of its members who give evidence of specified technical qualifications. It is believed that this departure, by establishing for the first time a " hall-mark " by which those with technical knowledge of illumination can be identified, will in the future pave the way for the recognition by Government Departments, local authorities, and large commercial organisations of the need for expert advice on lighting problems. We may therefore hope that in time all such bodies will have at least one qualified lighting engineer in their service.

The lighting movement is one which is growing throughout the world. Lighting service bureaux are established in India, Australia, New Zealand, Malaya, and South Africa, and the writer has the pleasantest recollections of visitors from our sister nations in the British Commonwealth and of discussing with them the expansion of the lighting field.

Most countries now have their illuminating engineering societies, and many have a close liaison with our Society. We watch the activities of the movement in Australia, New Zealand, and in many ways envy the I.E.S. of America with its nation-wide organisation.

It may be recalled that in 1939 Mr. Percy Good, when president, paid a visit to Australia and New Zealand and made welcome contact with the illuminating Engineering societies in these distant parts of the British Empire. We have since watched with sympathetic interest the progress of these sister societies, and in particular the movement towards a federal union of the three bodies now established in Australia.

The outbreak of war has naturally made intercourse difficult, but we have treasured greatly the many expressions of sympathy, affection, and goodwill from our friends and fellow-craftsmen in sponsoring the proper use of light.

The writer has vivid personal recollections of pleasant and informative visits to the United States, in the course of which he had opportunities of studying the enterprise of their society and the vast resources of their lighting industry. It is our hope that more intimate relations may be established between all the illuminating engineering societies in the Old World and the New.

When the victory of freedom-loving peoples has been won we may well find that the distances between continents can be bridged much more readily and that new opportunities will open up for common enterprises in serving our fellow men through the medium of light.

Additions to List of Members.

The following applicants have been duly elected by the Council to Membership in the Society and their names have been added to the list of members*:

CORPORATE MEMBERS:—

Clement, J. .....74, Moor Road, Gosforth, NEWCASTLE-UPON-TYNE.

Dickenson, H. .....Reay Brass Foundry Co., Ltd., West Row, STOCKTON-ON-TEES.

Green, J. K. .....28, Nuns Moor Crescent, Fenham, NEWCASTLE-UPON-TYNE.

Hall, J. G.....35, Clovelly Avenue, Grainger Park Estate, NEWCASTLE-UPON-TYNE.

Jolley, E. .....10, St. Mary's Avenue, WHITLEY BAY.

Kirkby, E. O. .....35, Belle Vue Bank, Low Fell, GATESHEAD.

Maben, T. P. .....21, Hawthorn Gardens, Kenton Estate, NEWCASTLE-UPON-TYNE.

Orchard, S. G. .....92, Bedminster Parade, Bedminster, BRISTOL.

Robinson, W. .....75, Dagnall Road, Acocks Green, BIRMINGHAM, 27.

Rolph, J. .....35, Jesmond Park West, NEWCASTLE-UPON-TYNE.

Taylor, R. .....1, Harcourt Park, Low Fell, GATESHEAD-ON-TYNE.

Turner, W. E.....“ Burniston,” Greenhill Road, Carlton, NOTTS.

White, S. D. ..... Red House, The Crescent, Darras Hall, NORTHUMBERLAND

ASSOCIATES:—

Fair, R. E.....37, Clayworth Road, NEWCASTLE-UPON-TYNE.

Probst, Mrs. M. B. ...“ Addington,” London Road, Batheaston, SOMERSET.

* In accordance with the present procedure the names of applicants for membership are published in THE TRANSACTIONS as soon as such applications have received the approval of the Council and the subscription for the current year has been duly paid.

Transference from Country Membership to Corporate Membership.

Brangwin, K. C. .....105, The Boulevard, Wylde Green, SUTTON COLDFIELD.

Baker, A. W. .....20, Alexandra Road South, MANCHESTER.

Bisson, G. .....21, Ladbrooke Road, Solihull, BIRMINGHAM.

Crammond, L. C. .....“ Rutlands,” Boundary Road, West Bridgford, NOTTINGHAM.

Freeman, C. F. .....Wood Lane, Shilton, Nr. COVENTRY.

Green, W. H. .....15, Frankley Avenue, Quinton, BIRMINGHAM.

Hare, L. A. .....8, Chatham Street, MANCHESTER.

Hoskins, C. H. .....27, Beacon Road, SUTTON COLDFIELD.

Loynes, W. A. .....25, Hillyfield Road, Erdington, BIRMINGHAM.

Nott, G. S. .....71, Shakespeare Street, COVENTRY.

Pimm, A. J. .....75, Robinhood Lane, Hall Green, BIRMINGHAM.

Pimm, E. A. .....25, Acheson Road, Hall Green, BIRMINGHAM.

Powell, F. .....“ Dormiston,” Cherry Hill Avenue, Barnt Green, BIRMINGHAM.

Reeves, C. J. .....312, Blossomfield Road, Solihull, Nr. BIRMINGHAM.

Swain, W. H. .....Russley, Brampton Road, Davenport, STOCKPORT.

Walsh, J. .....2, King Street, BLACKBURN.

Waygood, O. C. .....Lewis's, Ltd., Ranelagh Street, LIVERPOOL.

Forthcoming Meetings

Dec. 9th. MR. R. MAXTED on **Infra-Red Radiation and Equipment**; their Application in Industry *(I.E.S. Sessional Meeting to be held in the Lecture Theatre of the E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, London, W.C.2.)* **2.30 p.m.**

Dec. 4th. PROFESSOR T. DAVID JONES on **The History of Lighting in Mines** *(Meeting of the I.E.S. South Wales Group to be held in the Lecture Theatre of the Medical School, University College, Newport-road, Cardiff.)* **3.30 p.m.**

Dec. 11th. MR. H. C. WESTON on **The Industrial Lighting Revolution** *(Meeting of the I.E.S. North Western Centre, to be held in the Reynolds Hall of the Manchester College of Technology, Sackville-street, Manchester.)* **2.30 p.m.**

Dec. 17th. A Discussion on **Post War Reconstruction** *(Meeting of the I.E.S. Scottish Centre, to be held at “ The Gordon,” Gordon-street, Glasgow.)* **6 p.m.**

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—“Trans. Illum. Eng. Soc. (London).”